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RELATIONS BETWEEN SIMPLE AND COMPLICATED OXYGEN ACIDS[1]

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Introduction

The frequent failure of v-valent chemical elements, Q, to form acids H_vQO_v, or even anions QO_v^{v-}, is an outstanding example of how superficial irregularities in chemical behavior often conceal a grand underlying regularity. Once the simple oxygen acids are inclusively formulated as $H_{v-2n}QO_{v-n}$, it turns out that the simpler and more general behavior is that of $v-n$, and not that of either n or v. Most commonly, the value of $v-n$ encountered is 4, and the only other common values are 3 and 6. The former is typified by the sequence H_4SiO_4, H_3PO_4, H_2SO_4, and $HClO_4$.

The underlying chemical structural basis on which such regularities depend was worked out by Linus Pauling and others some three decades ago. Various $v-n$ values corresponded to various polyhedral arrangements of oxygen atoms around the central "acid-forming" atom Q in the anion QO_{v-n}^{2n-v}. Thus, for a $v-n$ value of 4, we have simple oxyanions that are externally tetrahedra of oxygen. In those exemplified above, 32 electrons are uniformly involved in the outer valence rings of the five component atoms of the anion.

It is important to inquire how far these structural bases and the consideration of quantities similar to $v-n$ can be applied to both simple and complicated oxygen acids, and to the anions and salts they form. First, simple oxygen acids will not be understood completely until their roles in the formation of complicated oxygen acids are understood. Second, the complicated oxygen acids are interesting; collectively, they form a tremendous and significant domain of inorganic chemistry. Finally, certain information common to both simple and complicated oxygen acids can only come from an inclusive delineation of the relations between them.

Nomenclature (Bulloff, 1956)

It is desirable to discuss relations between simple and complicated oxygen salts, and the anions and salts that they form, with a less cumbersome and more defined terminology than that now used. A refinement of suggestions originally made by Sydney Ross leads to the following rules:

1. Oxygen acids, their anions, and their salts shall be called, respectively, oxyacids, oxyanions, and oxysalts. These terms shall refer to species and classes defined below.

2. The simple oxygen acids, containing one atom of an acid forming element,

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Q, formulated as $H_{v-2n}QO_{v-n}$, their anions, QO_{v-n}^{2n-v}, and other ions and salts they form, shall be called, respectively, monoacids, monoanions, and monosalts. Monoanions have been called "monanions" for sake of euphony.

3. The complicated oxygen acids, containing a plurality, p, of atoms of one acid-forming element, Q, all with the same oxidation number, formulated as:

$$H_{p(v-2)+2(1-m)}Q_pO_{p(v-1)+(1-m)},$$

their anions, $Q_pO_{p(v-1)+(1-m)}^{p(2-v)+2(m-1)}$, and other ions and salts that they form, shall be called, respectively, polyacids, polyanions, and polysalts, with the exception that for $p=1$, $n=m$, and Rule 2 applies.

For $p=2$, the particular names are, respectively, diacids, dianions, and disalts.

For $p=7$, the particular names are, respectively, heptaacids, heptaanions, and heptasalts. For euphony, "a" can be undoubled.

For $p=p$, or for $p=\infty$, the particular and/or subgeneric names are, respectively, polyacids, polyanions, and polysalts.

4. The complicated oxygen acids containing a plurality, p, ($p=p_1+p_2+p_3+\ldots+p_h$), of a plurality of different kinds, h, (whether the difference be that of element, of valence or structural configuration state, or other ahylotropic difference) (Bulloff, 1953) of acid-forming atoms, Q (i.e., Q_1, Q_2, Q_3, . . . , Q_h), formulated as:

$$H_{p_1(v_1-2)+p_2(v_2-2)+p_3(v_3-2)+\cdots+p_h(v_h-2)+2(q-1)}(Q_1)_{p_1}(Q_2)_{p_2}(Q_3)_{p_3}\cdots(Q_h)_{p_h}O_{p_1(v_1-1)+p_2(v_2-1)+\cdots+p_h(v_h-1)+(1-q)},$$

their anions,

$$(Q_1)_{p_1}(Q_2)_{p_2}(Q_3)_{p_3}\cdots(Q_h)_{p_h}O_{p_1(v_1-1)+p_2(v_2-1)+p_3(v_3-1)+\cdots+p_h(v_h-1)+(1-q)}^{p_1(2-v_1)+p_2(2-v_2)+p_3(2-v_3)+\cdots+p_h(2-v_h)+2(q-1)},$$

and other ions and salts that can be formed from them, shall be called respectively, heteroacids, heteroanions, and heterosalts.

For $h=1$, Rule 3 applies.

For $h=2$, the particular names are, respectively, diheteroacids, diheteroanions, and diheterosalts.

For $h=3$, the names are, respectively, triheteroacids, triheteroanions, and triheterosalts.

For $h=h$, or for $h=\infty$, the names are respectively polyheteroacids, polyheteroanions, and polyheterosalts.

5. Hetericity, h, is denoted before polyicity, p, in naming.

$H_6Te(MoO_4)_6$ is a diheteroheptaacid.

$H_5I(MoO_4)_3(WO_4)_3$ is a triheteroheptaacid.

$P(W_3O_{10})_4^{---}$ is a diheterotridecaanion.

$(NH_4)_7Ge(VW_2O_{10})(V_2WO_{10})(W_3O_{10})_2$ is a triheterotridecasalt.

6. Neither the hetericity nor the polymericity need be denoted where the name adequately does so.

The diheteroheptacid above is hexamolybdatotelluric acid.

The diheterotridecanion above is tetrakistritungstatophosphate.

7. Where the stoichiometry or structure is not known, or where the known or assumed composition or structure cannot be at present fitted to IUPAC or other accepted nomenclatural system, the name given, while not attempting to innovate a maximal description, shall endeavor to describe all the characterizing features possible that shall not interdict future definitive naming.

   Thus, the triheteroheptacid above may be an accidental 50 mole-percent mixture, or it may be a part-symmetrical ordered displacement. It could be described as a molybdo-tungsto heteroperiodate. Naming the triheterotridecasalt above, were it possible with present limitations of the versatility of IUPAC nomenclature, would probably be less convenient and more confusing than would be the use of the formula instead of a name.

The rules given above, and the special difficulties inherent in the field of this paper, are both observed in the following discussion of the relations between simple and complicated oxygen acids and their derivatives or constituents.

Polyanionization: General

As will be seen in the sequel, aqueous formation of complicated oxyanions, be they heteroanions or any polyanions, follows two general patterns. One is a solvolytic pattern akin to that in the dissociation of simple oxygen acids and in the ionization of simple salts. The second pattern is similar to that occurring in condensation polymerization to form chain, sheet, and net polymers. The possible processes of formation and their aspects can be considered as a single phenomenon of "*polyanionization.*"

Three general routes can be postulated for polyanionization. Since the formulae would be similar, it is not necessary to depict separately the more complicated and particular process of *heteroanionization.* These three routes, written in the simplest way, are:

$$pQ_{v-n_1}^{2n_1-v} + 2[p(1-n)+(m-1)]H^+ \rightarrow Q_pO_{p(v-1)+(1-m)}^{p(2-v)+2(m-1)} + [p(1-n_1)+(m-1)]H_2O$$

$$pQ_{v-n}^{2n_2-v} + 2[p(n-1)+(1-m)]OH^- \rightarrow Q_pO_{p(v-1)+(1-m)}^{p(2-v)+2(m-1)} + [p(n_2-1)+(1-m)]H_2O$$

$$p_1QO_{v-n_1}^{2n_1-v} + p_2Q_{v-n_2}^{2n_2-v} \rightarrow Q_pO_{p(v-1)+(1-m)}^{p(2-v)+2(m-1)} \quad (\text{For } p_1+p_2=p;$$

$$m=p_1(n_1-1)+p_2(n_2-1)+1).$$

When the Arrhenius dissociation of water is remembered, it can be recognized that apparent pH restrictions indicated in the particular way of writing these equations chosen are indicative, but not mandatory. Other, and far more complex influences, govern the optimal pH at which a specified polyanionization should be carried out. In general, all three routes can be forced to a desired degree of completion by judicious use of common means for driving a chemical reaction to completion, wherever the desired polyanion can form.

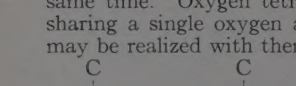
The above equations give no clue as to what polyanions can form. Such clues can come from considering what is already known about the ways in which oxygen polyhedra can be linked with each other.

Polyanionization: Oxygen Tetrahedra

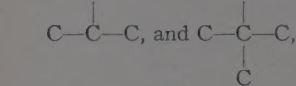
The polyanionization of oxygen tetrahedra, mentioned above for $v-n=4$ for common monanions, offers the classical example of this phenomenon. The classical illustration usually offered considers disilicate, chain silicate, sheet silicate, and network silicate and aluminosilicate formation and symmetry (Eitel, 1954). However, an easier introduction to the subject can be made to tetrahedral linking

by considering the chemistry of carbon, which has long been familiar to most chemists.

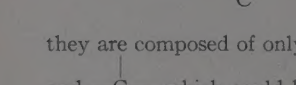
In carbon chemistry, tetrahedra may be joined at corners, edges, or faces, as denoted by the familiar notations, respectively, C—C, C=C, and C≡C. A linkage C≡C would imply that two carbon atoms occupy the same space at the same time. Oxygen tetrahedra only join together at corners, two tetrahedrons sharing a single oxygen atom at each corner joined. Thus, the structures that may be realized with them are only those that are analogous to C—C, C—C—C,



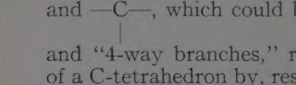
C—C—C, and C—C—C, etc. No matter how many of these structures we draw,



they are composed of only four kinds of "structural" units: C—, —C—, —C—,



and —C—, which could be termed, respectively, "ends," "middles," "branches,"



and "4-way branches," respectively involving joinings at 1, 2, 3, and 4 corners of a C-tetrahedron by, respectively, 1, 2, 3, and 4 distinct pairs of electrons. Analogous joinings at 1, 2, 3, and 4 corners of a 4-O-tetrahedron by, respectively 1, 2, 3, and 4 oxygen atoms may be similarly described (Van Wazer, 1958).

In considering the polyanionization of oxygen tetrahedra QO_4^{8-v}, to count each polyanion oxygen only once, corner-shared oxygens shall be considered as contributing $0_{0.5}$ to each oxygen tetrahedron in a polyanion. The valence, v, of the acid-forming element, Q, considered, sets limits upon whether the monanion can go all the way in the successive formation of ends, middles, branches, and 4-way branches, resp., $QO_{3.5}^{v-7}$, QO_3^{v-6}, $QO_{2.5}^{v-5}$, and QO_2^{v-4}. Thus, ClO_4^- can only polyanionize to ends, and can only form Cl_2O_7. SO_4^{2-} can polyanionize to ends to form the dianion $S_2O_7^{2-}$, disulfate, and to middles, which, with two ends, permit the formation of a gamut of polyanions from the trianion, $S_3O_{10}^{2-}$, trisulfate, to the ultimate polyanion $S_pO_{3p+1}^{2-}$, in the limit, SO_3, linear polymeric sulfur trioxide. PO_4^{3-} can polyanionize to ends, middles, and branches; as well as linear, branched and ring polyanions and polymers can form (ibid.). SiO_4^{4-} can give all these forms, and can readily polyanionize to "infinite" sheets and to infinite frameworks or nets of differing spatial "tightness." It can thus be seen that the numerical magnitude of v determines the versimilitude of structures possible for oxygen tetrahedra; similar valence-dependence versatility occurs for other oxygen polyhedra, e.g., pyramids, bipyramids, octahedra, Archimidean antiprisms, etc. However, the primary determinant of relations is the structural symmetry; the valence factor is only secondary. Thus, the other factors, n or m, and p are even more dependent factors. The neglected factor in the study of the relations of simple and complicated oxygen acids and their derivatives is the hetericity, h.

Heteroanionization permits the admission of an element, Q_1, of lower valence, v_1, into the polyanionization of the oxyacid derivatives of an element, Q_2, of a given valence, v_2. The structural unit $QO_{4-0.5x}^{v+x-8}$, where x is the number of corner-

shared O's in the 4−0 tetrahedron can, as has been shown entertain only the x-value permitted by the v-value. Lowering the mean v-value, $\frac{p_1v_1+p_2v_2}{p_1+p_2}$ increases the x-value attainable sometimes. It only takes one oxygen atom join to cross-link two long polyanionized chains together. This fact is of great theoretical and practical importance both for understanding the bulk of terrestrial material and for creating new inorganic compositions. It is already well known in the domain of the silicates (Eitel, 1954), e.g., in the aluminosilicates and in the borosilicates, where the use of tervalent-element tetrahedra permits a multiplicity of network materials to be developed within any given one of the quartzitic structures.

Similarly, heteroanionization has been used to effect terdimensional polyanionization in phosphate-bonded ceramics components (Sheets, 1958). Aluminophosphate "3-way superbranches" were deliberately created to remedy the inability of monheteric phosphoanions to form 4-way branches. In the extreme, the structural unit $AlPO_4$ can crystallize or aggregate in all the ways that the structural unit SiO_2 can, in the solid state, in solution, and in polyphase hydrothermal systems. Polyheteroanionization would probably be even more powerful and versatile in creating inoriganic systems than diheteroanionization.

General Study of Oxyanionic Compounds

The chemistry of some elements is known better than that of others, and for a given element, the chemistry of one of its monanions may be better known than that of another. Similarly, where polyicity is a natural phenomenon, as in the silicates of rocks, minerals, and ores, or where it is of technological interest, as in the phosphates, polyphosphates, polymetaphosphates, and ultraphosphates, interest in the polyanions of some elements exceeds that for other elements. Accordingly, we are still far from a general and complete understanding of monanion and polyanion chemistry.

For heteroanion chemistry, the situation is even less satisfactory. Interest has been small, study has been scanty, definitive findings have been few, and it can be immediately seen that the heteroacids and their derivitives form a vastly larger and more complex field of study than that of all the monoheteric monanions and polyanions put together. It seems likely that as the polyanionization properties of monanions and the heteroanionization properties of monanions and polyanions become better known, that it will be increasingly recognized that before the chemistry of any oxyanion can be understood thoroughly basically, there will have to be a general understanding of oxyanion chemistry for any degree of polyicity and hetericity.

There are already some striking indications of how the study of hetroanions has elucidated the nature of a polyanion in such a way as illuminate the polyanionization of monanions. In figure 1, the heteroanions listed were determined by x-ray crystallography to have the structures formulated. The stoichiometry thus confirmed reflects that of the monanions that provide the central atom of the polyanion. What is surprising is that although WO_4^{2-} and MoO_4^{2-} are electronically and spatially similar, and resemble each other otherwise chemically, in one heteroanion the outer unit coordinated is a trianion, and in the other a monanion. In the polyanion column it can be seen that there is a distinct difference in the polyanions from which the listed heteroanions form. Solution studies have failed to indicate why similar monanions form different polyanions and heteroanions. They have failed to yield structural information. For the polyanions, x-ray diffraction structural information only fell into a meaningful pattern once similar information gave more definitive results for the structure of

the heteroanions. Thus, $Mo_7O_{24}^{6-}$ is isostructural with $Te(MoO_4)_6^{6-}$; it is $Mo(MoO_4)_6^{6-}$, more appropriately a hexamolybdatomolybdate than a hepta-molybdate, and it is noteworthy that while the central Mo atoms of the ligand tetracoordinate 4−0 tetrahedra, the central central Mo atom hexacoordinates a 6−0 octahedron from the six ligand tetrahedra. The isostructuralism of $W_{12}O_{40}^{8-}$ and $P(W_3O_{10})_4^{3-}$ is even more startling; the former is $(W_3O_{10})_4^{8-}$ with a hole where the latter has a P^{5+} inserted. While tetracoordination seemingly prevails everywhere, the central 4−0 tetrahedron is formed by oxygens, but the outer W_3O_{10} groups are not linear trianions with a middle joined to the center, but are so arranged that WO_6 octahedra are formed which in turn trace out the 12 corners of a cuboctahedron.

The obvious conclusion is that since isostructuralism can exist for compositions of different hetericity, as in the monanions, steric factors are more primary than hetericity. However, hetericity is a means of establishing the steroechemistry of oxyanions.

Refer again to figure 1; the incredible heterosalt formulated seems at first sight to be tetraheteric. However, it contained originally (Rogers, 1903) 11 V^V atoms per V^{III} atom; this would indicate that it is pentaheteric. In solution, one or another of the other atoms present may have accepted some V^{III} electrons, for the $V^{V/III}$ ratio seems to be 13. This may indicate that some forms of the compound are hexaheteric. However, the solution color, and this behavior are compatible with the assumption that the heterosalt is a berthollide (Bulloff, 1953); it is then possible that in principle we might have to understand polyheteroanions in order to explain simpler oxyanions. The relations of simple and complicated oxygen acids to each other are too complex to be more than foreshadowed in this paper.

Particular Study of Heteroanions

In performing experiments intended to show relations between simple and complicated oxyacid derivatives, one must consider the vastness of the field of study marked out by the possible range of polyicity and hetericity if the experiments selected are to be meaningful. Figure 2 shows that the compositional range to be considered leaves out only the noble gases.

As yet, it seems that all chemically active elements can form heterosalts, most of them in a variety of anionic and cationic forms, and many of them in a number of valence states, both usual and unusual. For many candidate structures already known from minerals, or else synthesized in the laboratory, it appears likely that for discrete polyicities alone there will be a multitude of integral-atom compositional variations possible up to a degree of polyhetericity far exceeding any now known.

Thus, the sampling at the potential compound-field of heterosalts, so as to find system among the heteroanions, and among the complicated oxygen acids they could come from or lead to, is a task that could well be lightened. Techniques and approaches that work with small-sized compound fields and simple compounds become either much too slow or too uncertain when applied to large-sized compound fields and to complicated compounds. Indeed, to assure any rate of progress at all, once the simplest ground has been broken, requires the early determination of broad, if not ultimately accurate, working principles, and the location of typical situations and relations for parts of the field of study. Best of all is the early location of a structural rationale that permits the employment of simple structure-unit conceptions and the assumption of an unvarying backbone against which they are to be employed. This is how organic chemistry, the

compound-field of the derivatives of the "carbanes," came into being and progressed as a fruitful field of study. In beginning a study of heterosalts, chemists have yet to range sufficiently far over them. Much would be gained if this preliminary ranging could establish short cuts for further effort. It is the aim of

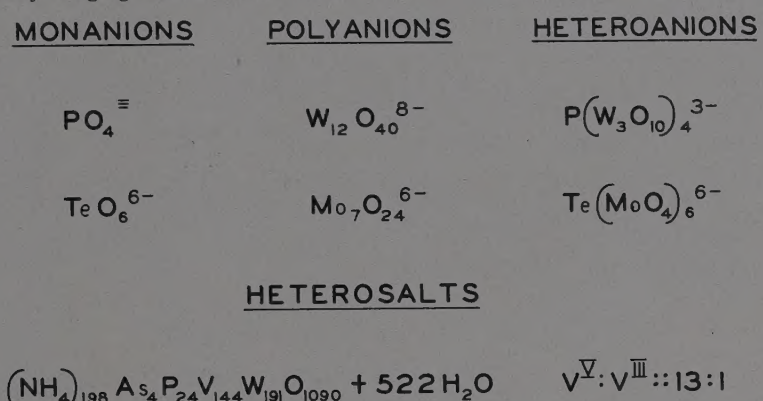


FIGURE 1. Oxyanions

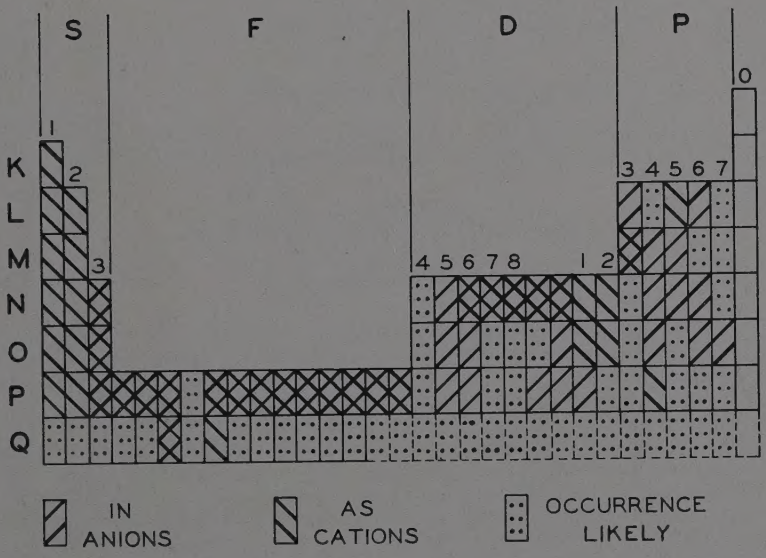


FIGURE 2. Heterosalt constituents.

this paper to show how such short cuts can be uncovered and applied to heteroanion study.

In a complicated and subtle field of study, where slow, definitive techniques such as x-ray crystallography have to be applied with the greatest of care, it might seem brash to consider short cut techniques, particularly those which do not even

involve the use of quantitative analysis. The justification is that these definitive techniques face difficulties when applied to the study of heterosalts that make them either inapplicable or uncertain except for favorable situations or for circumstances that justify the usage of considerable manpower and expense.

Condensation of Anions in Solution

One area in the study of polyanionization that has already consumed considerable effort while only rarely producing unchallengeable results is that of the determination of ionic species in solution. Often polysalts denoted as having a given polyanion in the crystal, and as having an ultimate analysis consonant therewith, have on dissolving either formed another ion, or else the ion has survived definition by a variety of solution-study techniques. Sillén has often spoken of the vast detail that must be attended to before simple complex-ion solutes can be accurately described; the greater difficulties of dealing with more complicated hydrolysis-sensitive ions may explain the low rate of achievement to date in the study of polyanionization in solution.

$$2VO_4^{3-} + 2H^+ \longrightarrow V_2O_7^{4-} + H_2O$$

$$2VO_3^- + 2OH^- \longrightarrow V_2O_7^{4-} + H_2O$$

$$VO_3^- + VO_4^- \longrightarrow V_2O_7^{4-}$$

$$\sim\!\!\!\rightarrow \left[(E_1)_{e_1} (E_2)_{e_2} \text{-------} (E_{E-1})_{e_{E-1}} (E_E)_{e_E} O_x \right]^{\sum_1^E V_E - 2x}$$

$$|E| = \text{HETERICITY} \qquad \left|\sum_1^E e_E\right| = \text{D.P.}$$

FIGURE 3. Condensation.

Figure 3 contrasts the formation of a simple divanadate ion with a simplified formulation of a polyheteropolyanion. The three over-all polyanionization routes for divanadate are shown; vanadium was selected as the example because almost every chemist has been exposed to the classical example of chromate polyanionization, which, since no oxyanion "meta" to the "ortho" chromate exists, has engendered a belief that oxyanion formation is favored only by acidic environment. At the outset, much of the solution study has reflected this orientation in that monanions "ortho" to the probable products that would form have been selected for study, together with a strong acid medium favoring ionization reversal in polybasic acids. Consequently, the number of ionic species present in a single polyanionization has been multiplied unmanageably.

Since heterosalts are often extremely soluble, and frequently highly hydrated, isolating them as formed has often been difficult, and what isolations have been made were not demonstrably those of salts whose anions had been in the solution. Even had this not happened as often as it did, there were reasons why quantitative analysis often failed to give even qualitatively correct results when applied to polyanions and heteroanions.

Limitations of Chemical Analysis

Figure 4 shows two analytical limitations that are common in polyanions; they can be worse for heteroanions. The first is that polysalts or polyacids form numerous hydrates, and, being polybasic, are subject to chemical dehydration as well. Three series of hydration metamers are given, and in each column four species that have been claimed as a definite chemical species in one publication or another are listed. The second is that as more complex stoichiometric ratios are encountered, the analytical precision needed to assign correct formulae becomes less likely to be attained. In a phosphoarsenovanadatomolybdatotungstate, one would expect intercomplexing effects to make the degree of precision of any analysis low.

Figure 5 lists other techniques either difficult to apply quantitatively or to interpret quantitatively when applied to any but fortuitously apt selections of heterosalts. Some of these, however, are useful for short cut work. Two that are particularly useful are light absorption and x-ray powder diffraction. If the solid and solution absorption are quite similar, and if the absorption observed can be tied to the diffraction pattern observed, then the probability that destructive hydrolysis is interfering with the study pursued is somewhat minimized.

HYDRATION METAMERS

$H_8W_{12}O_{40} + 2H_2O$	$H_8W_{12}O_{40} + 5H_2O$	$H_8W_{12}O_{40} + 8H_2O$
$H_{12}W_{12}O_{42}$	$H_{10}W_{12}O_{41} + 4H_2O$	$H_{24}W_{12}O_{48}$
$H_6W_6O_{21}$	$H_4W_8O_{26} + 4H_2O$	$H_2W_2O_7 + 2H_2O$
$H_2W_2O_7$	$H_2W_4O_{13} + 2H_2O$	H_2WO_4

COMPLEX RATIOS

$Na_6W_7O_{24}$	$Na_{10}W_{12}O_{41}$	10/6 = 1.67	12/7 = 1.71
$Na_{18}W_{22}O_{75}$		18/10 = 1.80	22/12 = 1.83

FIGURE 4. Analytical limitations.

Useful Short Cut Procedures for Heterosalt Study

Figure 6 gives some useful short cut procedures for the study of heterosalts. Some of these overlap, but each has its rapid diagnostic uses.

X-ray powder diffraction can be used to "fingerprint" polyanionization products. Line position shifts and line intensities both vary with the size and strain of crystallites, and care has to be taken that improper awareness of these two effects does not lead to the false differentiation of identical heterosalts or to the failure to differentiate between different but similarly structured heterosalts. The role of x-ray powder diffraction will be brought out by the examples of specific study given below.

Spectrophotometry and visual observation of color coupling can both be used in studying the formation of strongly colored polyanions and heteroanions. The

former is better adapted to study of polyanionization products while the latter is most convenient for watching the progress of the polyanionization reaction.

The other short cuts are involved with experimental design rather than with techniques used in experiments, and will be discussed below.

Experimental Test of Utility of Short Cut Procedures

As shown in figure 7, triheteroanions were selected for testing the possibility that laboratory work using short cut procedures could give results that would guide more definitive work or that by themselves would uncover a good deal of knowledge for the effort involved. The results presented cover the equivalent of about one man month of research effort; before triheteroanions were selected

PHYSICAL METHODS	STRUCTURAL METHODS
EQUILIBRIA	POWDER DIFFRACTION
ION PROPERTIES	SINGLE CRYSTAL X-RAY
COLLIGATIVE METHODS	LIGHT ABSORPTION
CRYSTALLOGRAPHY	NUCLEAR RESONANCE
HYLOTROPY	NEUTRON EFFECTS

OTHER TECHNIQUES

FRACTIONATION
SALT FORMATION
DERIVATIVE FORMATION
PARALLEL SYNTHESIS
THERMOGRAVIMETRY

FIGURE 5. Other limitations

POWDER DIFFRACTION	FIELD STUDY
VISUAL ABSORPTION	SUB-FIELD SELECTION
COLOUR COUPLING	COMPONENT STANDARDS

ISOMORPHOUS SERIES

CORROBORATIVE INCIDENTALS

PARTIAL PRODUCTS

FIGURE 6. Short cuts.

and made, however, much more effort was spent making preparations and x-ray powder diffraction photographs of possible precursor monanions, polyanions, and diheteropolyanions so that reactions could be traced, contaminants could be identified, and structural similarities could be detected. Once such preliminary work, which is a part of the facility needed for study has been completed, then it can serve permanently for further work, and each bit of study accomplished eases the path of future studies. It is probable that hundreds of heterosalts can be surveyed per man year in any ordinarily equipped chemical laboratory having access to x-ray and spectrophotometer equipment.

Triheteroanions were selected because proof of chemical individuality and knowledge of chemical structure were lacking for oxyanions more complicated than diheteroanions. To avoid monanions that could possibly polyanionize to networks, or which were prone to give high polymer degrees of polyicity (D.P.), only high-valent elements were selected. To avoid oxidation-reduction complications,

highest-valence state elements that were not vigorous oxidants were employed. This, and other considerations, limited the "field" of the experiment to that shown in figure 7.

If cross-group triheteroanionizations only are considered, the 7 elements of the field yield 7 polyanionization systems, 16 diheteroanionization systems, and 12 triheteroanionization systems. By deferring the study of Nb and Ta, the sub-field shown in figure 7 results; this yields 5 polyanionization systems, 8 diheteroanionization systems, and 4 triheteroanionization systems.

This sub-field was studied in a manner introduced by Allen Rogers (1903) almost six decades ago. Ammoniacal synthesis solutions were used; the OH^- route, which also favored "meta" formation initially, was probably followed initially (Bulloff, 1955). The ammonia was boiled off; as products built up, alkaline degradation and hydrolysis were possibly avoided. As neutrality was reached, perhaps some "ortho" formation resulted, and possibly the "orth"-"meta" combination route was also followed.

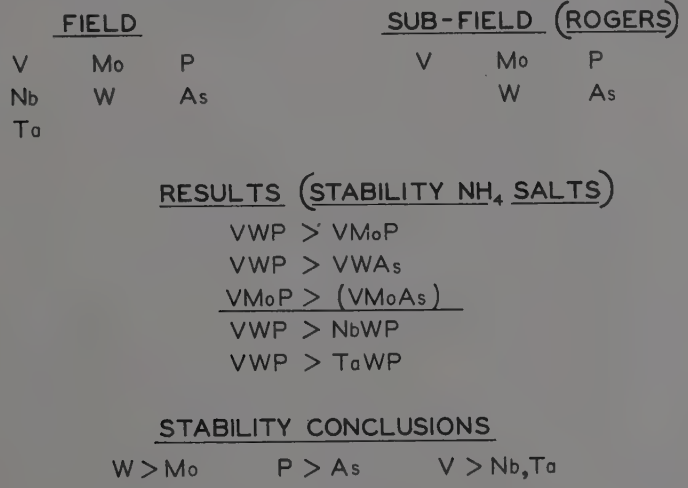


FIGURE 7. Triheteroanion test

The originally colorless-to-yellow solutions turned orange and then red as the boiling of the mixed monanions progressed. The rate of color change was associated with the ease of formation of product. The tungstovanadophosphate was always completely red in 2–3 hr. The yield was extremely high, and a pure product seemed to result. Molybdovanadophosphate solutions were completely red in 3–4 hr; yields were lower, but still high. Tungstovanadoarsenate solutions took 4–5 hr to reach a lighter shade of red; the products were contaminated with about 1% of orange polyvanadate. This impurity was picked out of preparations under a magnifier to secure purer products. Repeated attempts to prepare the molybdovanadoarsenate by this means failed, even after 280 hr of boiling. Yellow molybdoarsenate precipitated during the course of the reaction, and was not altered subsequently.

Since the diheteroanionization products and polyanionization products coulp possibly be contaminants of the triheteroanionization products, the same procedure was employed for these "part" syntheses. In no instance was a red product obtained. Ammonium metavanadate, never observed as a contaminant in triheteroanionization with vanadates was commonly a contaminant in the dihetero-

anionizations, and later, metamonanionates were observed as contaminants in unsuccessful attempts to triheteroanionize niobates and tantalates by Roger's method. These experiments yielded unidentified polyvanadate, molybdovanadate, molybdotungstate, vanadophosphate, molybdophosphate, yellow insoluble molybdoarsenate, tungstophosphate, and tungstoarsenate, as well as the monanions. These, together with purchased ammonium monanionates, polyanionates, and

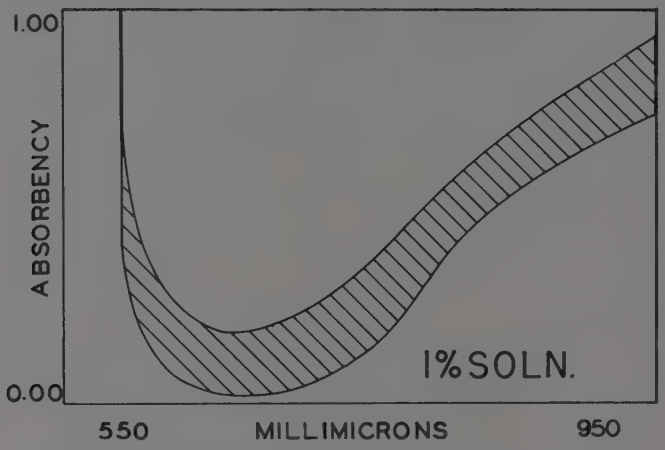


FIGURE 8. Spectrophotometry of crude triheteroanions.

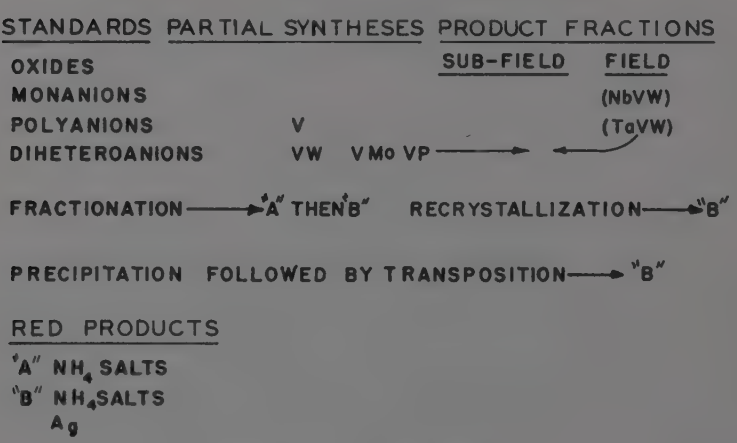


FIGURE 9. X-ray powder diffraction.

diheteroanionates of known composition were subjected to x-ray powder diffraction photography to secure a comparison with the triheteroanion products.

Taking times of formation, and apparent yields and purities as indicators, the stabilities inferred for the ammonium triheteranionates are indicated in figure 7. The attempted triheteroanionization of Nb and Ta gave lightly colored solutions.

One Ta preparation boiled for 580 hr yielded a small crop of black crystals with a triheterosalt diffraction pattern, possibly attributable to V impurity. The conclusion was drawn that under Roger's conditions Nb and Ta triheteroanionates did not form. The bulk of product formed was determined to be precursor tungstophosphate contaminated with, respectively, metaniobate, and metatantalate. Thus, the stability conclusions for individual elements as stated in figure 7 were reached.

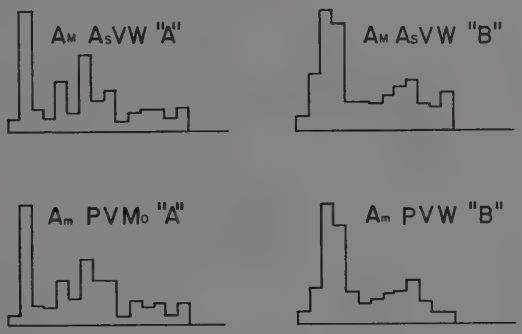


FIGURE 10. Diffraction characteristics.

"A"	"B"	"Ag"	AmVW	AmW
12.6	12.4	9.8	13.2	14
10.91	10.8	8.3	11.0	11
9.76	9.85	5.39	9.7	9.8
7.77	9.27	4.49	7.99	9.3
5.42	8.11	3.38	7.6	8.4
4.85	5.88	3.066	7.26	7.2
4.05	5.42	2.910	7.08	6.39

FIGURE 11. Principal spacings—Å.

A revealing side experiment was performed under Roger's conditions as follows. Normally the full red color of ammonium tungstovanadaphosphate was developed in 2–3 hr. When a maximum of ammonium phosphotungstate was used as the starting material, the red color formed in 0.4–0.6 hr. When vanadium pentoxide was used instead of ammonium metavanadate as the starting material, the 2–3 hr time was reproduced. When vanadotungstate was used no time change was noted, but when vanadophosphate was used, formation time was prolonged. Since the formation of ammonium phosphotungstate in these initially alkaline solutions was not confirmed, it was decided to follow the fate of ammonium phosphotungstate introduced into such solutions in the absence of vanadium. As far as could be determined, it was largely changed to the monanions. Thus the rapid formation noted above, and its implications require further study.

Spectrophotometry of Triheteroanions

As initially crystallized, and then totally dissolved without fractionation, the crude triheteroanion preparations all gave absorption spectra that fell in the shaded range indicated in the graph of figure 8. The refined salts all gave similar parallel spectral absorption curves.

X-Ray Powder Diffraction Patterns of Triheterosalts

The comparison procedure discussed above is schematized in figure 9. It was definitely concluded that trihetroanions had been formed, and that all those formed in a multiplicity of preparations were structurally similar. More convincingly, all of the triheterosalts prepared were dimorphous, and each of the two dimorphous series was an isomorphous series. The data for the "A" and "B" dimorphs are given in figures 10 and 11, along with other data.

In fractional crystallizations of triheterosalts to drop impurities and to establish hylotropy, the first head fraction from the crude synthesis solution was always the "A" dimorph. All subsequent fractions were the "B" dimorph. "A" and "B" mixtures were not observed. It seemed that possibly an impurity organized the nuclei that favored the "A" form; once "A" form was removed from the solution so it could not continue to be a "seed," only "B" form crystals could be obtained. Experiments designed to show that the "A" form was not itself an impurity, but that it was a dimorphic form of the same-structured diheteroanions also demonstrated that the "A" form was monotropically unstable.

Recrystallization of "A" dimorphs gave the "B" dimorphs. Both "A" and "B" gave the same visual absorption spectral curve. Both "A" and "B" forms gave silver trihetroanionates on neutral precipitation with silver nitrate that all had the same x-ray powder diffraction pattern. Transposition of the silver heterosalts with ammonium chloride regenerated only "B" ammonium triheterosalts. Dehydration of "A" and "B" salts showed a possible convergence of x-ray powder diffraction patterns with progressive water loss; however the patterns were increasingly collapsed as dehydration proceeded, and a firm judgment could not be made

Conclusions of the Short Cut Study

1. Tungstovanadophosphate, tungstovanadoarsenate, and molybdovanadophosphate, but not molybdovanadoarsenate triheteroanions are formed by Roger's boiling together of ammonium monanionates in initially strongly ammoniacal solution.

2. The ammonium triheteroanionates that result are dimorphic, with one of the dimorphs unstable with respect to the other.

3. The rates of formation observed visually and confirmed by yields obtained indicate that vanadium is triheteroanionized under conditions where tantalum and niobium are not, that tungsten triheteroanionized more rapidly than molybdenum, and that phosphorous triheteroanionized more rapidly than arsenic. The yields indicated that the stabilities of the triheterosalts formed may have been in sequence with the formation rates.

4. All the triheterosalt preparations had similar optical absorptions.

5. All the "A" dimorphs were isomorphous and isostructural with each other, and all the "B" dimorphs were isomorphous and isostructural with each other.

6. Both "A" and "B" ammonium heterotrisalts gave the same structured silver heterotrisalts which were transposable to reform only the "B" dimorph.

7. A facility for rapid survey of derivatives of complicated oxygen acids can be easily set up, and once operating, it can be used to classify or survey hundreds of heteropolysalts per man year.

Note

Surveys cannot be extrapolated too far from known structures or compositions. For some oxyanions, x-ray crystal study needed to establish a structure has taken years because the available salt has been of non-optimum symmetry. An immediate short cut contribution would be to seek by survey means a more symmetric less hydrated salt of a given oxyanion whose structure must be known to advance the base for extrapolation study.

Since the above work was done, an effect has been observed which could further be adapted to rapid survey of complicated oxygen acid derivatives. Normally, in x-ray powder diffraction photography of polyheterosalts, care is taken to use x-radiation whose wave length is not near the absorption edge of a constituent element. This is to avoid scatter effects, and "bad" pictures. However, if a "bad" picture is deliberately taken, and compared to a "good" one, it is often possible to establish whether the element with an unfavorable absorption edge has been taken into the product by a synthesis. In some instances, it is even possible to find line effects that hint at spatial relationships. For investigating heteroanions, it is recommended that "good" and "bad" pictures be compared. Thus, for study of tungstomolybdovanadoheteroanionates, it might be instructive to photograph each comparison specimen with copper, chromium, technitium, and rhenium x-rays.

SUMMARY

Relations between simple and complicated oxygen acids can only be completely understood in terms of a general knowledge of oxyanions. This same general knowledge is needed in order to complete our knowledge of simple oxygen acids.

The study of complicated acids and their derivatives can be expedited by short cut techniques adapted to survey procedures in order to make maximal use of the minimal amount of definitive structural information that can be made available in a limited time.

A tentative terminology has been suggested for complicated oxygen acids and their derivatives which has some advantages over present terminology.

ACKNOWLEDGMENT

Dr. Sydney Ross, Rensselaer Polytechnic Institute suggested shortening the accepted terms "Isopolyanions" and "Heteropolyanions" in order to remove definitional redundancies. Special thanks is hereby given to Drs. Benjamin Cloke, Walter Bauer, and Sydney Ross for facilities provided at the William Wightman Walter Laboratory for the performance of the experimental portion of the work.

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AQUATIC FUNGI IN SOME OHIO STREAMS

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INTRODUCTION

The collection of aquatic fungi in Ohio has been confined to one published study (Harvey, 1952) and the material to be reported below as far as the literature of Ohio mycology is concerned. Because of ubiquity, we may assume that at least two species of these fungi occur in the state according to distribution records in the 1937 monograph of the Saprolegniales (Coker and Matthews, 1937). Studies in Michigan and Wisconsin have yielded lengthy lists of aquatic fungi but similar studies have not been of interest to Ohio workers. The following list of such fungi, found by the writers in an attempt to discover whether a relationship exists between polluted water and the aquatic fungi which may occur there (Cooke and Bartsch, 1959), is presented as a contribution to the lengthening check lists of fungi found in Ohio. Certain concurrent records from the Potomac River in Maryland related to the same question are included here. The streams and their various sampling stations are described fully in the cited paper by Cooke and Bartsch.

In addition to fungi found during the sampling efforts of the writers, those reported by Harvey are included in this listing. Several other records are included in order to bring the list up to date.

TECHNIQUES

The technique used by Harvey was relatively simple. A stream sample consisting of water and stream bed materials was placed in a culture dish in the laboratory and sterile cracked hemp seeds were added. Within several days, if aquatic fungi were present, their zoospores reached the hemp seed and there developed a colony in the form of a halo around the seed. This mycelium could be subcultured on fresh hemp seeds in sterile water in which carbon had been boiled and filtered off, or it could be subcultured on corn-meal agar slants. In the studies reported here, other techniques were used, involving the use of some kind of bait. Sterilized carbon water was found to be adequate for use as described above as far as contamination is concerned.

After a colony had developed on hemp seed for at least one, sometimes two weeks, it was in a robust state actively producing many sporangia and sometimes oogonia with oospores. In this condition the relatively fresh cultures of saprolegniaceous fungi frequently were transported to others for identification or checking of identifications. Either cotton or folded laboratory tissue was moistened, a hemp seed with its colony placed upon it, the tissue folded, the total wrapped in paper toweling and numbered. When preparing cultures for shipment, the primary wrapping material was damp enough so that it would not dry out in transit but not so wet that it would moisten the glue holding envelopes together. The group of cultures wrapped in paper toweling could be wrapped again in wax paper or aluminum foil and this package could be placed in a box, culture tube mailing can or envelope for mailing. Upon receipt of such material by cooperating specialists, the parcels were opened and planted again with fresh hemp seed. Usually, in the case of cultures wrapped in cotton, too many cotton fibers prevented immediate study while ones wrapped in tissue could be observed directly on being refloated in water.

At first, the baits used were enclosed in cylinders made of one-quarter inch

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mesh hardware cloth, stoppered at each end with corks. From one of the corks a steel wire skewer holding a piece of beef, a piece of apple, a whole date, or a rose hip or hawthorne fruit projected into the cylinder. The cylinder, floating partially submerged, was tied to some more or less permanent object on the shore and left for a week. Then the baits were transferred to a container filled with water from the sampling location, returned to the laboratory, and placed in sterile carbon water with sterile cracked hemp seed. Another technique followed a suggestion by Höhnk and Bock (1954). Bags of loosely woven nylon cloth, containing sterile, cracked hemp seed, were tied to the shore of the stream being sampled, and left for three days. These bags were returned to the laboratory in containers partly filled with water from the sampling site.

In one series of tests, aluminum tea balls were prepared in the laboratory by adding cracked hemp seed, assembling three on a string, wrapping, and sterilizing. These assemblies then were sent to a field survey team working on a tributary of the Potomac River. Each tea ball contained three hemp seeds and a multiple unit as described was used at each of six stations. One tea ball from each site was removed from the water after 2-, 4- and 6-day exposures. The tea balls, or their contents, were wrapped in absorbent tissue paper, then in absorbent toweling, the whole tagged and sent by regular mail to Cincinnati. In most cases, water molds were recovered from these collections by the use of fresh hemp seeds.

On the basis of this experiment, tea balls were used for the remainder of the test series. They were allowed to remain in the sampling station for 3–5 days depending on work schedules of persons involved in setting out and recovering samples. Experience showed that the shorter period of exposure was preferable.

Annotated List of Aquatic Fungi Isolated in Polluted Water Tests

Blastocladiales—Blastocladiaceae

Allomyces *spp.*—Isolated from soil samples obtained from clay bottom of basin dug near Lebanon, Ohio, as part of a stabilization pond sewage treatment system.

Isolated from contaminant of excess fish food in an aquarium at the Sanitary Engineering Center, Cincinnati.

Harvey reported isolating strains of this genus from Station 5.2 on Lytle Creek, Lytle Creek tributaries and from the East Fork of the Little Miami River and its tributaries.

Saprolegniales—Saprolegniaceae

Achlya *spp. nonsporulating.*—Isolated from stations 6 and 14 in the Potomac River, Maryland, following two days' exposure of hemp seed in tea balls and following 6 days' exposure. In Mill Creek, Ohio, it was found at station 4 in October, and in June it was isolated from stations 1, 2, 3 and 4. At one or more of these stations it was obtained on hemp seed, apple, human skin and insect larvae.

Achyla ambisexualis *J. R. Raper.*—Isolated from Mill Creek, Ohio, in October and June. In October it was found at station 1 on hemp seed, and in June it developed on hemp seeds at stations 1, 2 and 3.

Achlya americana *Humphrey.*—This was our commonest species of *Achlya* and was found on the Potomac River, Maryland, and in both Mill Creek and the Little Miami River in Ohio. On the Potomac River it was picked up at station 6 after 2 and 6 days' exposure of hemp seeds, at station 7 after 2 days, at station 14 after 2 and 4 days, at station 16 after 2 and 6 days, and at station 19 after 4 and 6 days' exposure of hemp seed in tea balls.

On the East Fork of the Little Miami River this species was isolated from water and on whole date bait on Nov. 18 and 25 below Batavia. At Williamsburg it was picked up in both sampling periods above town on apple, in the town on apple and date, and below the town on apple and date and it was isolated from water samples.

On Mill Creek this species was picked up in June at stations 1, 2 and 4 on hemp seeds, at stations 1 and 4 on apple, and at station 4 on human skin.

Harvey reported this species from the Lytle Creek basin.

Achlya bisexualis *Coker and Couch.*—Picked up in the Potomac River at station 6 after 2 days' exposure of hemp seed, and on Mill Creek in October at station 1.

Achlya dubia *Coker.*—On the East Fork of the Little Miami River this species was found above Williamsburg on apple, and below Williamsburg in a water sample. In Mill Creek it was collected at stations 1 and 2 on samples of human skin.

Achlya flagellata *Coker.*—Found at station 9 on the Potomac River after 2 days' exposure of hemp seed.

Harvey reported this species from station 8.7 on Lytle Creek, from tributary streams of Lytle Creek, from Stonelick Creek and from the east fork of the Little Miami River and its tributaries.

Achlya oblongata *de Bary.*—Found once on Mill Creek in October at station 4.

Achyla prolifera *C. G. Nees.*—On the Potomac River this species was isolated from station 16 after 2 days' exposure of hemp seed, and from station 19 after 4 days.

Aphanomyces laevis *de Bary* (?)—Found by Harvey at stations 4.2, 6.5, 7.6 and 8.7 on Lytle Creek, and in the Great Miami River near Ross (Venice).

Aphanomyces parasiticus *Coker on* Achlya americana *Humphrey.*—Found once at station 1 on Mill Creek in June.

Brevilegnia diclina *J. Harvey.*—Reported by Harvey from stations 5.2, 6.0, 7.6, 9.3 and 10.4 on Lytle Creek, from tributaries of Lytle Creek, Todd's Fork, Stonelick Creek and Reservoir, Cowan Creek, the Little Miami River, the East Fork of the Little Miami River and its tributaries, and the Great Miami River at New Baltimore and Miamitown.

Brevilegnia subclavata *Couch.*—Reported by Harvey from station 7.6 on Lytle Creek and from the East Fork of the Little Miami River.

Dictyuchus anomalus *Nagai.*—In the Potomac River at station 19 this fungus was found after 4 days' exposure of hemp seeds in tea balls.

Dictyuchus monosporus *Leitgeb.*—Isolated from the Potomac River on hemp seeds exposed at station 6 for 2 and 6 days, station 14 for 4 and 6 days, station 16 for 6 days, and station 19 for 2 and 6 days. At Lytle Creek, Ohio, this species was picked up on baits at station 7.2 in September, and at station 7.6 in January. On the East Fork of the Little Miami River this fungus was picked up on apple bait both above and below Batavia. At Williamsburg it was found at all sampling points. It was picked up on apple above town, on apple and date in town and below town on apple and date baits. On Mill Creek it was found in June at stations 1, 2 and 4 on hemp seeds exposed in tea balls.

Dictyuchus *sp.*—Harvey reported strains with and without oospores from stations 1.0, 5.2 and 8.7 on Lytle Creek, tributaries of Lytle Creek, Todd's Fork and the Little East Fork of Todd's Fork, Cowan Creek, the Little Miami River, and the Great Miami River at New Baltimore and Miamitown.

Geolegnia inflata *Coker and Harvey in J. Harvey.*—Reported by Harvey from the Lytle Creek Basin, Todd's Fork and Cowan Creek.

Geolegnia septisporangia *Coker and Harvey in J. Harvey.*—Reported by Harvey from station 7.6 on Lytle Creek.

Isoachlya *sp. nonfruiting.*—Obtained from station 19 on the Potomac River after 2 days' exposure of hemp seed.

Saprolegnia *sp. nonsporulating.* Isolated from the Potomac River at station 14 after 2 days exposure of hemp seeds. In September on Lytle Creek this fungus was found on apple bait at stations 1.0, 2.8, 7.2 and 7.6; on dates at stations 1.0, 2.8, and 6.5; on meat at stations 1.0, 2.8, 4.2, 5.2 and 7.2; and on rose hips at stations 5.2, 6.5 and 7.2.

Saprolegnia delica *Coker.*—At Lytle Creek this fungus was found in September on rose hips at station 2.8, on dates at stations 4.2 and 7.6; and in January on several baits at stations 5.2, 7.6 and 8.7.

Harvey reported this species from stations 7.6 and 8.7 on Lytle Creek, Lytle Creek tributaries, Todd's Fork, Stonelick Lake, East Fork of the Little Miami River, a roadside spring near Lebanon and a small stream at Bridge No. 43, U. S. 22, near Montgomery, Ohio.

Saprolegnia diclina *Humphrey.* Found in the Potomac River at station 6 after 6 days exposure of hemp seeds, and at station 14 after 2 days exposure.

Saprolegnia ferax (*Gruith.*) *Thuret.*—Collected on Lytle Creek in September on apple at stations 4.2, 5.2 and 6.5, at stations 4.2 and 8.7 on rose hips, on meat at stations 6.5, 7.6 and 8.7, and on dates at station 9.7; and in January at stations 1.0 and 7.6 on several baits. On the East Fork of the Little Miami River this species was found both above and below Batavia on apple, date and meat baits and in water samples. At Williamsburg this was found above, in and below the town on apple, and date baits and in water samples.

Harvey reported this species from stations 5.2, 6.5, 7.2 and 7.6 on Lytle Creek, Lytle Creek tributaries, Todd's Fork, and the West Fork of the East Fork of the Little Miami River.

Saprolegnia ferax-mixta *group.*—Several cultures isolated from hemp seed exposed in the Potomac River have been assigned here. These were obtained at station 6 after 2, 4 and 6 days' exposure, and at station 7 after 2 and 4 days' exposure. Two unidentified strains of *Saprolegnia* were obtained by Harvey in the Lytle Creek Basin and on tributaries of the Little Miami River.

Saprolegniales—Leptomitaceae

Leptomitus lacteus (*Roth.*) *Ag.*—Occasionally material assignable tentatively to this species has been found intermingled with other aquatic fungi. It has not yet been obtained in pure culture. Lytle Creek in September on rose hips at station 2.8, on dates at station 4.2 and on apple at station 7.6, and in January at stations 2.8 and 8.7 on various baits. On the East Fork of the Little Miami River this was found at Batavia above town on apples and dates, and at Williamsburg in town on apple bait.

Lagenidiales—Olpidiopsidiaceae

Olpidiopsis fusiformis *Cornu on* Achlya americana *Humphrey.*—This fungus is an internal parasite in the mycelium of its host. It was found once on Mill Creek at station 2 in June.

Olpidiopsis saprolegniae (*Braun*) *Cornu on* Saprolegnia ferax.—This parasite was found at Potomac River station 6 after 4 days exposure of hemp seed.

Olpidiopsis saprolegniae *var.* levis *Coker on* Saprolegnia ferax.—Found once on hyphae of the host in the East Fork of the Little Miami River in Williamsburg on date baits.

An olpidiaceous parasite on *Dictyuchus monosporus* was found after exposing hemp seed at station 19 in the Potomac River for 6 days. Material was inadequate for further study.

Peronosporales—Pythiaceae

Pythium debaryanum *Hesse.*—Harvey reported isolating this species from Lytle Creek tributaries, Cowan Creek, the East Fork of the Little Miami River, and from the Great Miami River at New Baltimore.

Pythium torulosum *Coker and Patterson.*—Harvey reported isolating this species from Cowan Creek and from the East Fork of the Little Miami River.

Pythium ultimum *Trow.*—Harvey reported isolating this species from Cowan Creek and from the East Fork of the Little Miami River.

Pythium *sp.*—Found in the Potomac River at station 6 after 2 and 6 days exposure of hemp seed, at station 9 after 2 days exposure, and at station 19 after 4 days exposure. On many attempts to recover water molds from Lytle Creek samples, using hemp seeds in bottom deposits brought to the laboratory, several strains of this genus have been found but were not traced to species because most species in the genus are identified partly on the basis of association with a host plant in the soil.

Harvey reported isolating unidentifiable cultures of *Pythium* from the same streams reported under *P. torulosum.*

Peronosporales—Zoopagaceae

Zoopagus insidians *Sommerstorff.*—Appearing occasionally in activated sludge systems at Sanitary Engineering Center as reported recently (Cooke and Ludzack, 1958).

SUMMARY AND CONCLUSIONS

In view of the number of aquatic fungi reported from North America in the literature of the water mold specialist, and in view of the wide diversity of stream

conditions and aquatic habitats in Ohio, it is suggested that much information could be obtained on the populations of these organisms within the state. Streams flowing from glaciated to unglaciated areas, crossing new valleys through the older glaciated areas, and flowing through the hills in unglaciated areas traverse wide varieties of geological formations each of which affects the stream in one way or another. Farm ponds, fishing lakes, recreation lakes, and natural lakes as well as roadside ponds, ditches and streams, could furnish the collector or observer with a wide variety of habitats. Aquatic fungi also occur in soils and this field is completely untouched in Ohio. From upland beech forests and fields resulting from their clearing, to Cedar swamps, undisturbed hemlock forests, limestone canyons and sandstone conglomerates, to coal mines and the acid seepage and drainage waters issuing from them as well as in intermediate areas of many kinds, there are many habitats which deserve careful study.

As a corollary to the present study an attempt was made to obtain chitrids by the use of pollen affixed to slides in petroleum jelly. Probably because of the short exposure period no success was experienced. However, this technique could be tried in a number of habitats using a number of variables to determine something of the population of such organisms in the state.

It is suggested that persons making surveys of any type of body of water for aquatic fungi of any kind record water quality data as part of the survey to show something of the habitat and to aid in pollution studies. Additional suggestions include varying the length of exposure time in the field, method of sampling, types of bait, types of bait holders, comparisons of the validity of bringing habitat to the laboratory and taking bait to the habitat, populations at different depths in a lake in relation to the water zones within the lake, and any other factor which appears essential to a fuller understanding of our knowledge of aquatic fungi in their environment.

ACKNOWLEDGMENTS

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POLLEN ANALYSIS OF THE MICHILLINDA PEAT SEAM

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The Michillinda peat seam is exposed along the shores of Lake Michigan, near Muskegon and thus lies about 60 miles north of the South Haven seam studied by Zumberge and Potzger (1955). It consists of about 50 in. of peat lying on gravel and sand over silt and is overlain by dune. The basal layer has been dated at 5250 B.P. (M–473) and the top at 4100 ± 250 B.P. (M–472). It thus represents about 1000 yr of accumulation and approximates, perhaps accidentally, the rate of peat accumulation calculated by Sears and Jensen (1933) for the Erie basin. We are indebted to Professor James Zumberge for the opportunity to study this material, and to the National Science Foundation for financial assistance.

Results of our analysis are shown in detail in table 1. As indicated by the column of total counts, pollen was very scarce in some layers, the peat at certain depths being heavily diluted by sand as shown in figure 3. Carbonized plant remains are also abundant, particularly in the sandy layers, but whether they are due to fire or decomposition (muck formation) we cannot say. Our main conclusions have been drawn from those spectra representing a count of more than 100, although in general the lower counts confirm the higher ones.

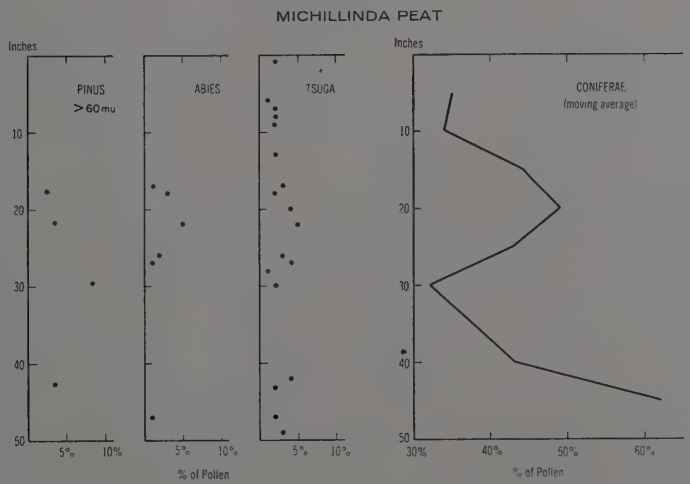

FIGURE 1. Decreasing trend of conifer pollen. Abundance at 20 in. due to mesophytic Abies and Tsuga.

While we have on file a conventional diagram of the profile, we believe that the essential results can be visualized more simply from the accompanying figures 1 to 3. All are based on the 19 analyses (out of 50 made or found negative) that registered more than 100 grains tallied.

At the right in figure 1 is drawn the moving average (0–10 in., 5–15 in., etc.) for total percentage of conifer pollen.

At the left, in separate columns, are entered the profiles of white or red pine (*P. strobus* and/or *resinosa*), fir (*Abies*), and hemlock (*Tsuga*), respectively. The

TABLE 1

Pollen analysis—Michillinda peat seam

Depth	Conifer.	Decid.	NAP	Counts	Abies	Cupress.	Larix	Picea	Pinus	Tsuga	Acer	Alnus	Betula	Carya	Castan.	Fagus	Ilex	
0–1	48	39	13	271				14	33	02	14	07	01	02		01	01	
1–2	45	39	16	31				26	19		16			03		06		
2–3	41	41	19	37				05	32		14			03				
3–4	55	39	06	18				06	50		28							
4–5	23	65	12	142				01	22		23	06	02	07	01		04	
5–6	26	57	17	326		01		07	17	01	25	07	02	03		01	02	
6–7	45	43	12	173			03	09	31	02	21	05	01	02			01	
7–8	35	55	09	182			01	03	29	02	23	01	02	08	02	01	01	
8–9	33	54	13	216		01	01	04	25	02	16	05	03	02	02	03	02	
9–10				0														
10–11	20	71	09	35					20		23		09			09	03	
11–12	42	47	11	76		03		08	28	04	09	07	03	01		09		
12–13	31	57	12	167		01	03	01	24	02	07	04	07	02		12	01	
13–14	34	61	05	64		03	05	09	14	03	25	02		03	02	11	03	
14–15	47	45	08	86	02		01	21	20	02	14	02	01	02		05	02	
15–16	36	55	10	73	03	08			22	03	19	10			04	05		
16–17	49	42	09	212	01	03	01	08	34	03	16	03		02	01	03		
17–18	54	39	07	322	03	02	01	13	34	02	12	03		02	07	03	01	
18–19				10					100									
19–20	64	28	08	53		04		17	40	04	08			04	02	08		
20–21	53	47		15				07	47		07	40					07	
21–22	54	37	09	146	05			12	32	05	10	04				05		
22–23				0														
23–24	42	55	12	131				04	38		13	08	02	06	08	01	04	
24–25				0														
25–26	48	45	07	282	02	02		12	29	03	14	05		03	04	04		
26–27	44	47	09	265	01	02	01	08	29	04	18	06	01	03	02	03	01	
27–28	31	55	14	172		01	01	05	25	01	24	09	02	02	02	02	01	
28–29				0														
29–30	38	54	08	719		01	01	03	31	02	14	11	01	02		02		
30–31	31	48	21	52					29	02	13	17		04				
31–32	37	54	08	83			01	08	27	01	18	18		04		01		
32–33	45	48	07	96				08	33	03	20	18						
33–34				6														
34–35				0														
35–36	58	25	17	12					50	08	17	08						
36–37	49	47	04	73				07	42		11	05		07	10			
37–38				0														
38–39	50	50		8					50		37							
39–40				0														
40–41	55	39	06	51			02	02	48	04	18	02		06		04		
41–42	55	33	12	156		01		01	49	04	01	03		01	05		01	C
42–43	32	53	14	187			02	06	22	02	23	03	01	01	12	02	01	
43–44	46	38	15	91		02	02	07	27	08	02	04			05	03		
44–45				0														
45–46	53	47		17				12	41		06				33			
46–47	71	25	04	134	01	01	01	16	48	02	10	04				01	01	
47–48	74	21	05	38			03	18	47	05	08	05						
48–49	89	10	01	103		05	02	06	73	03	02	02	01				01	Ny
49–50	79	09	12	43				47	33		02			02				

TABLE 1—(Continued)

Depth	Liquid.	Quercus	Salix	Tilia	Ulmus	Chenop.	Compos.	Cyper.	Drosera	Ericac.	Gram.	Myrioph.	Nuphar	Polyg.	Typha	Unknown	Spores
0–1		10			04	01	04	01			04	01 A				02	04
1–2		15					06									10	
2–3		19			05		11				05					03	
3–4		11					06										
4–5		13			07	01					04	01 A	01 R			05	02
5–6		11		01	06	02	03	02	01 M	03 L	02	01 A	01 R	02 P	01 Cp	01	01
6–7		09			05		04	01		01 L	03		03		01 Cp		04
7–8	01 J	13			04		02	01		01	02		02	01		01	04
8–9	02 J	11	06		02	01	02	01			03		01	04		02	03
9–10																	
10–11		20	03		06		03				06						06
11–12		08	04		07		03				01		04	01		01	03
12–13	01	15	03	01	05		06	01			01		01	01		02	02
13–14		14			02		02	02								02	05
14–15		14			05		02	01			03			01			01
15–16		11	04		01	03	03				03			01			03
16–17		09	01	01	04	01	01				06			01		01	05
17–18		07	01		04		02	01			02			02		01	06
18–19																	
19–20		02			06		02	02					04				
20–21																	19
21–22		12	04		01		02	02			01		01			01	03
22–23																	
23–24		08			05		03	01		02	02					04	06
24–25																	
25–26		08	03	01	03		02	02			01		01	01		01	04
26–27		07	01	01	04		02	01		01	02		01		01	01	03
27–28		06	03		04	01	05	02			02	01	01			02	04
28–29																	
29–30	01	18	02		03	01	02	01			02	01	01		01	01	02
30–31		08			06		02				10		02			08	06
31–32		13									06		01			01	02
32–33		07	03				02				05						02
33–34																	
34–35																	
35–36							17										
36–37		11			03		01									03	08
37–38																	
38–39			13														
39–40																	
40–41		10					02				04						06
41–42		22					03	02			07						
42–43		06	02	01	02		01	02	01		03					07	03
43–44		16	04	01	01		03	06			01		02	01		02	02
44–45																	
45–46		06															41
46–47		07	01		01						04						07
47–48		03	05					03			03						13
48–49		04									02						
49–50			05			02	02	02			02				02		

A=Artemisia C=Corylus Cp=Caprifoliaceae J=Juglans L=Labiatae M=Malvaceae Ny=Nyssa
P=Polygala R=Rumex

steady decline in conifer percentage from bottom to top is evident, as is the increase in mesophytism between the 30- and 20-in. levels. The absence of sand between these levels also indicates good vegetative cover.

Figure 2 shows the moving average of deciduous percentages. At the left is the profile for beech (*Fagus*) and at the right that for nonarboreal pollen. This figure shows the steady increase in deciduous forest and the climax of the humid, mesophytic trend that begins at the 30-in. level, here manifested by the beech maximum at 12–13 in.

Figure 3 shows by means of vertical bars the range of various arboreal genera through the profile. These have been arranged in order of their successive maxima as indicated by the curve connecting these maxima. The profile begins with predominance of jack pine (*P. banksiana*), Cupressineae (*Juniperus* and/or *Thuja*), chestnut (*Castanea*) and oak (*Quercus*). These predominantly xerophytic indicators then give way to the mesophytic vegetation as already noted between 30 and 10 in. Warming above the 30-in. level is suggested by the disappearance of fir, the advent of sweet gum (*Liquid ambar*) and possibly holly (*Ilex*), also the traces of walnut (*Juglans*) at 7 to 9 in.

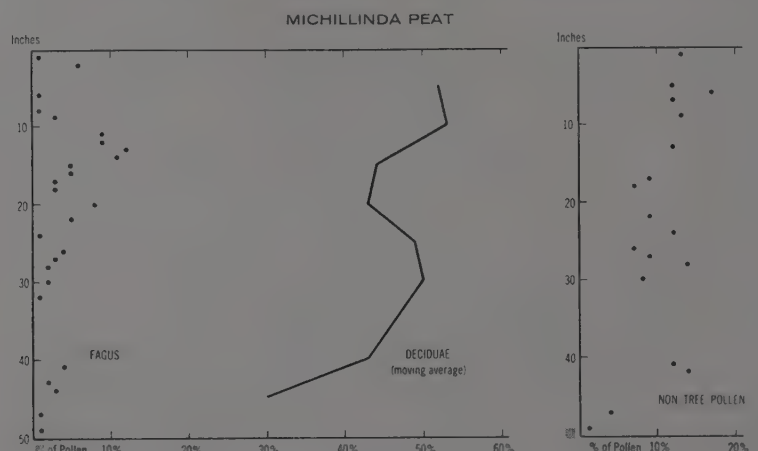

FIGURE 2. Increasing trend of deciduous trees. Fagus indicates mesophytic conditions. Nonforest pollen at right.

Changes above the 10 in. level are less diagrammatic. The renewal of sand movement, the maximum of hickory (*Carya*) and elm (*Ulmus*) and a high percentage (17%) of nonarboreal pollen at 5–6 in. suggest increasing dryness. This we would normally expect, for previous studies in the Great Lakes area show that the beech maximum was followed by one of oak-hickory. Hickory and elm, with their relative intolerance of shade do not follow beech in normal succession. We also consider the high percentage of NAP on the low count levels at 1–3 in. as significant of dry conditions. Spruce, alder, holly, larch, and willow show equivocal patterns. All are swamp or bog forms, the spruce in question being principally *Picea mariana*. Favorable habitats for them may persist throughout upland succession and be initiated between dunes by blowing sand. Maple could be either the mesophytic upland sugar maple (*Acer saccharum*) or, as is more likely in this instance, the swamp red (*A. rubrum*). In any event, the record of these genera does not vitiate the essential significance of the profile as sketched.

In chronology and climatic character it agrees with the upper half of the South Haven peat described by Zumberge and Potzger (1956), leading from the pine period that includes a date of 6330 ± 400 to a time just preceding the Xerothermic, and representing a warm, moist interval between two dry ones (Sears, 1931; Potter, 1947). According to Zumberge and Potzer, it began at the time of minimum level of Lake Chippewa in the Michigan basin and continued through rising lake level to a time just preceding the Nippissing.

Sand activity below the 30–in. level, so marked that good counts between 30 and 40 in. were not possible, confirms our evidence of initially dry conditions marking the end of the pine period. It could have been intensified by an increased sand supply due to the then low lake level.

Significance of sand activity between the 5– and 16–in. level is less clear. Despite the mesophytic conditions at 12–13 in. there may have been an increasing supply of adjacent beach sand due to rising lake level. It is curious that sand

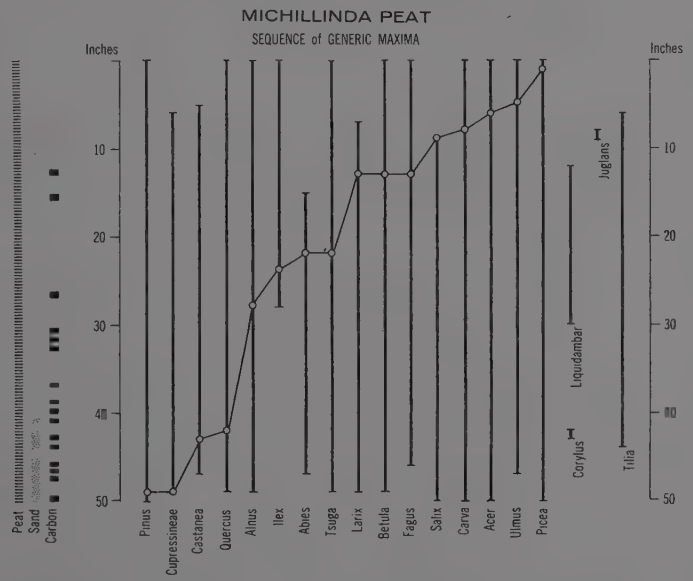

FIGURE 3. Presence of forest genera indicated by vertical lines, levels of abundance maximum by circles.

deposition does not occur from 5 to 0 in. which we predicate as a time of increasing dryness. We can only suggest that the more xerophytic vegetation had, by that time, fairly stabilized the surface. After this lull the deposit was buried by dunes.

The profile suggests some interesting botanical problems that may later yield to improved techniques and the accumulation of further evidence from south and west. An example is the problem of migration of chestnut. This genus, once abundant in the East and in the Ozark region, has been separated from southern Michigan by a calcareous barrier in northwestern Ohio (Transeau and Williams, 1929). Was its early appearance in the Michillinda and South Haven profiles due to northward movement in the Mississippi basin during the pine period or has it some other explanation? Perhaps a reexamination of the material analyzed

by Voss (1934) in the Chicago region before modern techniques were in use might aid in solving this and other problems of plant migration and climatic history. Certainly his interpretation of relatively uniform postconiferous conditions does not agree with evidence now available from Iowa, Indiana and Ohio.

SUMMARY

The Michillinda peat seam near Muskegon, Michigan, despite its frequent low pollen counts, affords a classic record of the mesophytic interval, from about 5000 to 4000 B.P., between the pine period (Deevey's B) (1939) and the oak-hickory xerothermic (Deevey's C2). It also records climatic conditions accompanying the rise in the Michigan Basin from the Chippewa low water stage to the time just preceding the Nippissing stage of the great Lakes.

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The Mammals of North America. *E. Raymond Hall* and *Keith R. Kelson.* Ronald Press Co., New York. 2 Vol., xxx+1083 pp. $35.00.

The publication of Hall's and Kelson's MAMMALS OF NORTH AMERICA is an event of tremendous importance to everyone with an interest in mammalogy. No one working in this field can afford to be without access to a set of these books. It is a monumental work, carefully done, meticulously illustrated with pen and ink drawings and with readily workable keys. The books appear to have been most carefully edited. Discrepancies which I have noticed are few, indeed, and of a most trivial nature.

The work is wisely printed in two easily handled and durable volumes. Each contains a complete index in addition to the main part of the books. Volume one begins with a brief discussion of zoogeography and volume two ends with a short but excellent section on collecting and preparing specimens. Both are valuable additions.

Paper, printing, and binding are excellent, befitting a work of this kind. The price will prevent its purchase by many but the material contained is essential to any future work in this field and a wide distribution would seem assured.

E. E. Good

The Living Rocks. *Stevan Celebonovic, Geoffrey Grigson* and *André Maurois.* Philosophical Library, New York. No date: ca. 1957–58. 94 p., including 63 full-page B & W plates. $6.00.

Old Stone Age. *Stevan Celebonovic* and *Geoffrey Grigson.* Philosophical Library, New York. No date: ca. 1957–58. 96 p., including 64 pages of B & W plates. $10.00.

These two books are numbers one and two of a projected series on Nature and Art ". . . in which the camera is used by Stevan Celebonovic to interpret . . . the age-long interplay of nature and man." The apparent object is to share with the reader some of the marvels of nature and man through perfectly magnificent photographs of objects and artifacts, together with a commentary on the pictures and their significance by Grigson. Maurois has written a preface to the series. Although the pictures will be of interest to scientists, the commentaries are directed to the nonspecialist. *The Living Rocks* contains pictures of fine mineral and fossil specimens. *Old Stone Age* consists of pictures of artifacts, a few fossils, and many cave paintings. Although their prices may limit the incidence of these books in private libraries, they ought certainly to be in every library of earth science in order to be available for instruction and possible inspiration of students.

Malcolm P. Weiss

SHAWNEE NAMES AND MIGRATIONS IN KENTUCKY AND WEST VIRGINIA

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The name "Shawnee" is an English adaptation of the term *Shaawana*, by which the Shawnee Indians named themselves in their own language. Voegelin (1938–40: 318) lists *šaawanwa* 'Shawnee (tribe or individual),' adding *šaawanwaki* beside *šaawanooki* 'the Shawnee (plural).' Another white adaptation is *Savannah*, name of both the city and the river in Georgia, where, in the 1600's, Shawnee Indians were first encountered by Whites. *Eastern* Shawnee, that is. A *western* portion of the tribe lived, entirely separate from the eastern one, along the Cumberland River in Kentucky and Tennessee. Within only a few years of each other, before 1720, both halves of the Shawnee nation, hard pressed by warfare with other Indians allied against them, started to migrate. The eastern Shawnee wandered north, settled in Pennsylvania for a while, but, uprooted again, traveled westward and finally reached the Ohio country. Here, about 1750, they were united, for the first time in their history, with the western half of their tribe (Hodge, 1907, 1910: 535).

After 1720, these western Shawnee had migrated from the mouth of the Cumberland River in a general NEE direction, all over Kentucky, while some of their bands had crossed the Ohio and had occupied the entire stretch between the mouths of the Great Beaver River in western Pennsylvania and of the Scioto River. It had been known for a long time that the latter migration tended toward the east, but much had remained uncertain, if not entirely unknown, about the regions in Kentucky, through which these western Shawnee had passed, or where they had temporarily settled. In these pages, I will try to remove some of those uncertainties.

The first impulse for an approach to the matter came from Kentucky. Dr. Thomas P. Field, Department of Geography, The University of Kentucky, at Lexington, Ky., mailed to me a list of place and neighborhood names found in Kentucky, with the request to identify those of assured Indian origin. In the process, a few white adaptations of Indian names turned up, among them *Eskippakithiki* (Clark Co.), *Eskalapia* (Lewis Co.), *Tywhapita* (Hancock Co.), another *Tywhapita* (Hopkins Co.), and *Tyewhoppety* (Todd Co.), a white variant of *Tywhapita*. Even in English transcription, their language structure clearly marked them as Shawnee. Eventually, their true Shawnee forms will be presented and semantically analyzed in order to show their real English meanings.

According to Dr. Field's reliable Kentucky sources, the names here given name neighborhoods rather than places, with the exception of *Tywhapita* in Hopkins County. A hundred-year-old woman stated that, a long time ago, her village, Manitou in Hopkins County, had been called *Tywhapita*. Since there also exists a place called *Tywhapita* in Missouri, it is likely that the name was transferred by white settlers from the northern *Tywhapita*, in Hancock County, to their village in Hopkins County, and eventually to their new settlement in Missouri. That disposes of *Tywhapita* in Hopkins Co., Ky., as an area named by the Shawnee directly, but not of *Tywhapita* in Hancock Co., nor of *Tyewhoppety* in Todd Co.

The geographic situation, throughout Kentucky, of those Shawnee-named areas led me to assume that all of them had been stopping points for the western

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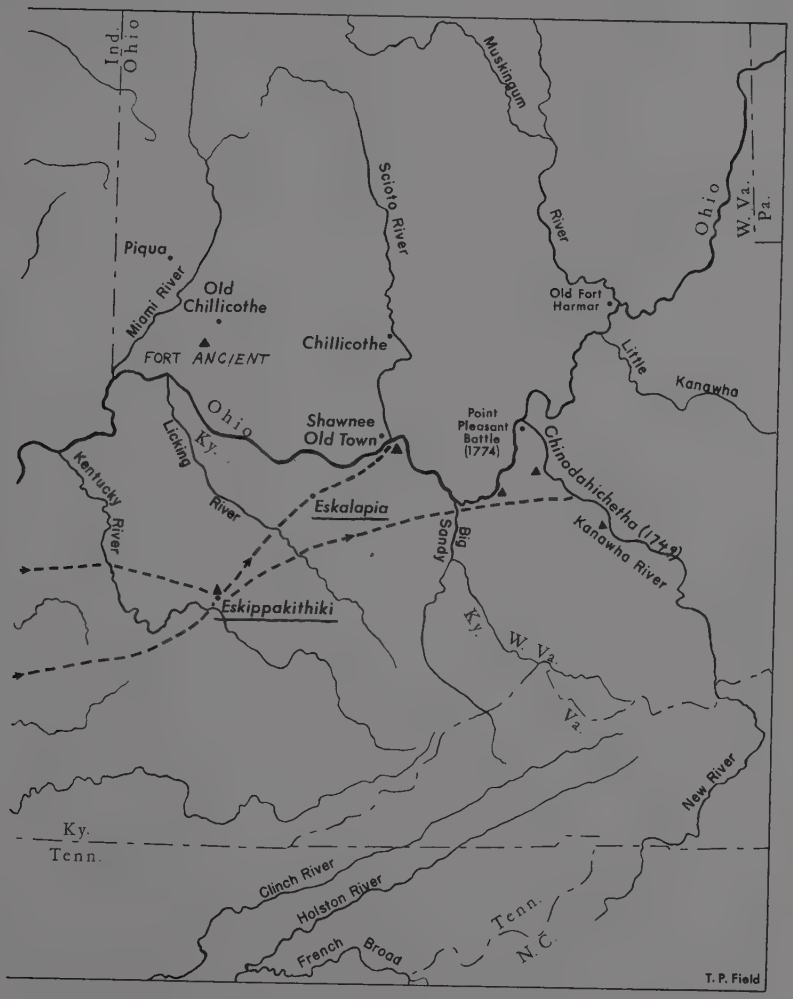
FIGURE 1. Map showing Shawnee migrations and place names.

Shawnee on their eastward migration through Kentucky when, after 1720, they had definitely moved out of their old home territory along the Cumberland River. (See fig.)

This opinion was strengthened by the striking fact that in their neighborhood late-prehistoric sites had been discovered, not only in Kentucky, but also east of it, at the Great Kanawha River, in West Virginia. Apart from a linguistic clue



which will be discussed later in this paper (page 162), Shawnee presence at the mouth of the Great Kanawha, in 1749, clearly shows that some bands of the western Shawnee must have continued their migration toward the Ohio country as far east as the Great Kanawha River.

Dr. W. S. Webb, emerited Professor in the Department of Archaeology and Anthropology, of the University of Kentucky, at Lexington, Ky., who himself

had excavated some of the Kentucky sites, has made the following statements about them.

Of the prehistoric site not far from *Tyewhoppety* in Todd Co., Ky., Dr. Webb has this to say (letter, April 17, '59):

> The Williams Site in Christian Co., Ky., 4 and ½ miles northwest of Trenton and about half way between Trenton and Pembroke may be a "Fort Ancient" site. The Todd Co. line runs within 300 yards of this site.

(See Webb et al., 1929). By "Fort Ancient," Dr. Webb seems to indicate the culture of the people who, between A.D. 1200 and 1600, placed their late-prehistoric village within the Hopewellian defense works of Fort Ancient in SW Ohio.

In a letter of April 23, '59, Dr. Webb states that he does not know of any Fort Ancient sites which have been reported from Hancock County. He adds that the University of Kentucky has done very little field work in Hancock Co., and that, consequently, it is not possible to say what might be found there. That makes *Tywhapita* in Hancock Co. the only one of the Kentucky localities along that migration route of the western Shawnee about which we possess no prehistoric data (see fig.).

With regard to *Eskippakithiki* (Clark Co., Ky.), Dr. Webb refers to Beckner (1932). He further comments (in the aforementioned letter) that he does not know of any archaeological investigations "of a scientific kind," that have been done there, "but such evidence as has been published may indicate Fort Ancient type of culture"; cf., Beckner (1932: 376–380) (see fig.).

It is most likely that, by way of the *Eskalapia* area (Lewis Co., Ky.), a Shawnee trail led from *Eskippakithiki* northeast to the Ohio River, whose south bank it reached at present South Portsmouth, just opposite present Portsmouth, Ohio. Here at the Fullerton Field, in Greenup Co., Ky., according to Dr. Webb (ibid.), ". . . a cemetery and village were excavated in 1926. The village was a Fort Ancient site. . . ." (cf. Webb et al., 1928: 106).

Where, at the lower course of the Great Kanawha River, the western Shawnee's other migration trail, from *Eskippakithiki* eastward, ends in western West Virginia (see fig. 1), there are late-prehistoric "village sites and small mounds whose occupants had a material culture closely related to that of the Fort Ancient Aspect" (Griffin, 1943: 240). J. B. Griffin (ibid.) regretted that

> . . . not a single one of these has been thoroughly excavated, and information regarding this area is based upon the work of the Bureau of American Ethnology in the latter part of the nineteenth century and upon reports given by amateurs who have collected in the area.

In no event, however, do I consider it a mistake to connect these finds, or the "Fort Ancient" sites near those Kentucky localities, with the Shawnee nation and its migration westward through Kentucky toward their historic territories along the Cumberland and the Savannah Rivers, respectively, at about A.D. 1600. In fact, this may lend considerable support to the supposition, already widely accepted, that the late-prehistoric (or early-historic) Fort Ancient-Village people were early-Shawnee.

It appears far from accidental that such 'prehistoric' sites of the "Fort Ancient" type have turned up along the route of the *western*-Shawnee's migration *eastward* through Kentucky and the Great Kanawha area of West Virginia, which I am discussing in these pages; that is, near *Tyewhoppety* (Todd Co.); possibly, near *Tywhapita* (Hancock Co.); near *Eskippakithiki* (Clark Co.); near the point where the *Eskalapia* trail (Lewis Co.) reached the Ohio River in Greenup Co., in northeastern Kentucky; and, finally, in the Great Kanawha region of West Virginia (see fig.)

Tribal traditions, more than a century old but not forgotten among the eastern or the western half of the nation, appear to have irresistibly driven the Shawnee

back to the Ohio country, from whence warfare with relentless opponents once had forced them to migrate. The endlessness of the return, and the time to accomplish it, were irrelevant: the final goal, and the direction toward it, remained unaltered throughout half a century and longer. That is true for both the western and the eastern Shawnee, who returned to Ohio by widely separate roads but at about the same time. So it was hardly fortuitous that, about 1750, the two halves of the nation were united, 'for the first time in their history,' in the Ohio country. They were not merely united, but *re*united.

As far as the *western* Shawnee are concerned, the general trend of the 'prehistoric' migration was merely reversed: this time, they wandered east, *towards* Ohio, rather than west, *away from* Ohio. But, as the prehistoric sites near the way-points indicate, through the *same* regions and by the *same* trails: they were on familiar ground (see fig.).

Apart from the prehistoric evidence, there are two main reasons for assuming that the locality names here mentioned marked the eastward migration route of the western Shawnee, through Kentucky, from the Cumberland to the Scioto. One of them is the occurrence of *Tywhapita* and *Tyewhoppety* in western Kentucky regions not too distant from the Cumberland River. The other is a historical fact, not significant in itself but essential for both the course and the chronology of that migration: the birth of the later Shawnee Grand Chief Catahecassa (Black Hoof) near present Winchester, Ky. (Hodge, 1907, 1910: 535), about 1740 (ibid.: 212). Later on, the Catahecassa story will be taken up again at greater detail.

Marking important points on that migration route, the names *Tywhapita* and *Tyewhoppety* make particularly good sense because of the original Shawnee name which underlies both the English adaptations: **Tθw/haap/ité*. It is a combination of Shawn. *tθw-* 'quitting' (Voegelin, 1938–40: 140); *-haap-* 'returning (from activity far from home)' (ibid.: 426); and *-ite* 'vague locus' (ibid. 151), approximately meaning 'somewhere around here.' Collectively, the compound signifies: 'somewhere around here (*-ite*), one quits (*tθw-*) returning home (*-haap-*).' Or, in better English, 'this is a point of no return.' But where is 'the home' to which there was no return from either *Tywhapita*, in the north, or *Tyewhoppety*, farther south? Most probably, it was the familiar settlement region of the western half of the Shawnee nation along the Cumberland River, flowing north from about present Nashville, in Tennessee, to its confluence with the Ohio at Smithland in Kentucky. It cannot have been a question of excessive distance since the straight line from *Tywhapita* to the nearest point on the lower Cumberland measures only 85 miles while the straight-line distance between *Tyewhoppety* and the nearest Cumberland point is only 50 miles. Not knowing the actual length of the trails used by the migrants, I cannot be more accurate. Of one thing we may be sure: neither measured by straight line nor by length of trail was either distance great enough to justify the name *Tθwhaapité*, 'point of no return home' (see fig.).

So there must have been a more compellent reason for it, and there was, indeed: warfare with the Chickasaw, their old and relentless enemies. According to the late James Mooney (Hodge, 1907, 1910: 534–535), the Chickasaw, allied with the Cherokee, pressing against the Shawnee and their territory from the south, persistently pushed the Shawnee north in the Cumberland valley and, by 1720, had succeeded in forcing them out of it. Seeing the future of their nation in the east rather than in the west the western Shawnee began to migrate gradually, in bigger and smaller bands, away from the Cumberland region, mainly in a general easterly direction. Some, however, must have turned north, and settled on the Illinois side of the Ohio, near the site of present Shawneetown, Ill. Evidently, they stayed there long enough to imprint their name on the neighborhood, but it is not exactly known what became of them.

Although the western Shawnee definitely did not migrate eastward in one column, yet their individual bands apparently operated under the directions of

one man, a Chief, or even a Grand Chief, for it is most unlikely that they moved along with no instructions from some sort of headquarters. *Θwhaapité*, 'here one quits returning home,' for instance, appears like a message from one in command to his tribesmen on the march, issued to two migrating bands wandering away, one delaying in the north, and one, farther south. It sounds like a definite order *not to return* '*home*' from the place where they happened to stay. They saw the point and wandered eastward.

A migration of that kind imposed no particular hardships upon these Shawnee, who, in true Algonkian style, were on the march anyway most of the time. They roamed their hunting-grounds, hunting and fishing, and whenever the need arose, they stopped over at a given place long enough to plant their maize and raise a crop, or, if there were reasons, even longer. To have these rights to the use of their hunting-grounds go uncontested by any other Indian tribe was their brand of 'security.' 'Time' was not of the essence; they had all the time they wanted and needed: days, weeks, months, years, decades, generations (Loges, 1956): 58).

To be more to the point, it should be said that in 1714 Charleville, a French trader, established himself among the western Shawnee on the Cumberland, near present Nashville, Tennessee. He reported that, even then, they had begun to abandon their settlements and to move down the Cumberland valley toward the north, hard pressed by a war with combined Chickasaw and Cherokee forces (Hodge, 1907, 1910: 535). Rather than engage in battle with the enemy's superior field strength, the Shawnee, certainly not cowardly but with their effective Algonkian strategy, fought a clever withdrawing action, northward first along the Cumberland as far as the river mouth, and then, moving away from it toward the heart of Kentucky, in an eastern direction (see fig.).

Everything points to a communication between the western Shawnee and the eastern half of the nation in Georgia, in those years, for it cannot have been merely incidental that slightly earlier, about 1707, the eastern portion of the Shawnee had likewise begun to abandon their territory in the south, and to migrate north toward Pennsylvania. Here, they eventually allied themselves with the Delaware, their Algonkian cousins, for combined action against the Cherokee (ibid.). Much as they hated the Whites, both the eastern and western half of the Shawnee, being seasoned diplomats, had never been scrupulous about the sources of their tribal security, whether Indian or white. In 1715, at a treaty, at Philadelphia, between the Pennsylvania government and the eastern Indians, the western Shawnee were represented by delegates. At a council, held with the Delaware, they asked the friendship of the Pennsylvania government for the western Shawnee, "who live at a great distance" (ibid.). It must have taken these delegates considerable time to travel to Philadelphia from the Cumberland region, which in 1715 was still western-Shawnee territory. Only on a map as late as 1720 (Moll, 1720) is the mouth of the Cumberland marked as Cherokee territory, and an Indian settlement there, as 'Savannah Old Settlement'; indicating that the Shawnee have definitely left (Hodge, 1907, 1910: 535). As the future bears out, the Ohio country was the eventual goal of both the western and eastern Shawnee migrations.

It had been emphasized before that those people on their wanderings were concerned with nothing but the direction of their travel, time being utterly insignificant. Thus, it happened that, about 1730, some of the migrating bands of the western Shawnee appeared along the Ohio, in the southwest of western Pennsylvania, and in the southeast of present Ohio. Here, they stayed with the consent of the Wyandot, whose territory it was. Other western Shawnee, as it is known, according to Hodge, ". . . probably wandered for some time in Kentucky, which was practically a part of their own territory and not occupied by any other tribe. Blackhoof (Catahecassa), one of their most celebrated chiefs, was born during this sojourn in a village near the present Winchester, Ky" (ibid.).

This man was called 'Catahecassa' by the Whites. Probably, his true Shawnee name was **M·ʔkateewi·ka·ʔšá*, meaning 'black/hoof' (Voegelin, 1938-40: 359;

300[?]). As the time of his birth, 'about 1740' is given (Hodge, 1907, 1910: 212). But what is "this sojourn," during which the future Grand Chief was born "in a village near the present Winchester, Ky."? Fortunately, there exists reliable information on the area where this village was situated. The neighborhood name, unmistakably Shawnee, is *Eskippakithiki*, in Clark Co., Ky., 11 miles southeast of Winchester (see fig.). On the Topographic Maps of the region, it appears as "Old Indian Fields" over an area of about two square miles.

> The site is of relatively low relief and appears to the eyes as a valley when in fact it is a divide between the west flowing Howards Creek and the south flowing Lulbegrud Creek. The T. Pownall map [Pownall, 1776] gives an accurate location at an early date, possibly 1755. This location was occupied by a band of Shawnees in 1745–1748 and was last occupied by similar Shawnees in 1755 (Dr. T. P. Field; pers. letter, Nov. 18, '58)

Obviously, these Shawnee bands had settled there in order to raise their crops in that fertile region; also cf. Beckner (1932), a publication which not only demonstrates the pristine significance of *Eskippakithiki* as an agricultural Indian settlement, but also provides a clue to the probable "Fort Ancient" character of the prehistoric *Eskippakithiki* site and, thereby, to its early-Shawnee past.

Indirectly, the agricultural importance of *Eskippakithiki*, especially as a stop-over for western Shawnee on their migration to the east, is likewise confirmed by the semantic analysis of the Shawnee name form on which it is based: **Škipak/eθi/ʔki*. As no Shawnee term starts with a vowel, the name is to be regarded as a polysynthetic compound of Shawnee *škipaky-* 'blue, green' (Voegelin, 1938–40: 314); *-eθi-* 'all over' (ibid.: 335); and locative word-final *-ʔki* 'place where it is' (ibid: 330). Composite meaning: 'where it is green all over.' It perfectly fits that fertile blue-grass area which the white settlers later called "Old Indian Fields." Temporarily, the migrant Shawnee established village settlements in the region for planting and harvesting their maize. In one of them, so we are told, Chief Catahecassa was born. No Shawnee-named area is known between either *Tywhapita* or *Tyewhoppety*, the two 'points of no return home' in the west, and *Eskippakithiki*, the blue-grass region in east-central Kentucky; that is, on a straight-line distance of about 150 miles (see fig.). What trails the migrants used, and where or how long they stopped over, nobody knows. One fact is certain: western-Shawnee bands appeared about 1730 on the Pennsylvania and Ohio side of the Ohio River. So they must have covered the stretch comparatively fast, in about ten years (Hodge, 1907, 1910: 535). Others seem to have wandered, and stayed, in Kentucky a much longer time, twenty years or more. So long as the trend of their migration was to the east, time did not matter. The later 'home settlement' along the Scioto did not become a real fact until about 1750, after the western and the eastern Shawnee had united in the Ohio country. In 1748, the western Shawnee on the Scioto numbered only "162 warriors or about 600 souls" (ibid.). Thus, it is possible that the Shawnee bands who settled at *Eskippakithiki* in 1745 to 1748, and even as late as 1755 (Pownall, 1776), were still members of that long-drawn west-east migration. But this is undoubtedly true for those who had arrived there about 1740, when Catahecassa was born in the *Eskippakithiki* region, near present Winchester, Ky. (ibid.).

It is not known how long the band to which Catahecassa and his parents belonged delayed at *Eskippakithiki*. Probably, their migration proceeded in a general NE direction to a point on the Ohio where, across the river, at the mouth of the Scioto, other western Shawnee, since about 1730, had established a settlement. On a much later map (W. S[cull ?] 1765), it is shown as 'Shawnee Town formerly' (see fig.). The area through which that trail led was known to traveling Shawnee as **Škaalaappiyé*. Today, a white-man's transcription of the Shawnee name still exists in Lewis Co., Ky., as a neighborhood name, *Eskalapia*, surviving in *Eskalapia Mountains*, *Eskalapia Hollow*, etc. Folklore even has tried to connect

Eskalapia with Aesculapius, the Roman god of healing, for there also occur *Esculapia Springs* and *Esculapia* neighborhood. A semantic analysis of **Škaa laap piyé* reveals the real meaning of *Eskalapia*. It is a combination of Shawn. *škaa-* 'raw, soft, wet' (Voegelin 1938 40: 314), with *-laap-* 'the same repeated,' that is; 'over and over' (ibid.: 345), and *-piye* 'long-extended area' (ibid.: 101). Composite meaning: 'long-extended area (*-piye*), over-and-over (*-laap-*) raw, soft, wet (*skaa-*).' It indicated to the migrants that the trail, at a long stretch, traversed a weed-covered, soggy terrain; in brief, that the land was unfit for a stop-over and the planting of corn.

There is evidence, however, that some western Shawnee bands of about 1740 continued their migration from *Eskippakithiki* in a general NEE direction as far east as the Great Kanawha valley in present West Virginia; that is, for a distance of roughly another 130 miles, straight line (see fig.). Only indirectly has it to do with the fact that Catahecassa later fought as a Shawnee war captain, in 1774, by the side of Grand Chief Cornstalk at Point Pleasant, at the mouth of the Great Kanawha, valiantly but unsuccessfully, for the Shawnee concerns against Col. Lewis, subcommander under Lord Dunmore.

In 1749, when Catahecassa was still a youngster, the western Shawnee appear to have occupied the fertile blue-grass bottom land near the mouth of the Great Kanawha river, to the equal annoyance of the Virginians and the French. Céloron, Sieur de Bienville, had been dispatched to North America by the King of France in order to claim the eastern Ohio valley for the French crown. Céloron believed that he had done that very thing when, in 1749, he had a few lead plates, declaring the conquest, buried near certain river-mouths at all four corners of the Ohio country. In 1846, one of these plates was unearthed at the mouth of the Great Kanawha, on the Virginia bank of the Ohio (Hatcher, 1940: 43). Eventually, it helped to confirm beyond the shadow of a doubt that, in the days of Céloron's visit, western Shawnee had possessed the territory at the lower Kanawha.

As one of the confines of the French conquest, there is inscribed on the Kanawha lead plate the name *Chinodahichetha*, preceded by the French word *Rivière*, indicating that here the Great Kanawha is meant. Written according to *English* phonology, it would read *Chinotahishetha*. Its ending, *-tha*, strongly points to Shawnee origin. Most probably, it derives from Shawn. **Či·noota hiši θa*, a compound of the personalizing prefix *či-*, marking 'an individual' (Voegelin, 1938 40: 143); *-noota-* 'guarding something (for someone else)' (cf., ibid.: 377); *-hiši-* 'belonging to self, matter-of-course possession' such as head, arms, legs, etc. (cf., ibid.: 457); and personalizing final *-θa*, approximately 'person acting, or being, as indicated' (ibid.: 335). Composite meaning: 'he who guards that which belongs to him.' As Céloron's *Rivière* clearly shows, the Shawnee term is part of a river name and, therefore, must receive the addition *θiipiʔkí* 'river (plus locative final *-ʔki;* ibid.: 330).'

But is it *really* meant to be *the name* of the Great Kanawha, from *the Shawnee's* point of view? According to the principle of practical purpose, such as strictly followed by Algonkian Indians giving names to streams and localities (Mahr, 1957; 1959), it certainly is not. The term **Činootahišiθá* contains no practical 'hint' of any sort, be it to travelers by canoe and trail or to migrants in quest for other Indian essentials.

It rather brings to mind Rev. John Heckewelder's high opinion of the Indians' sense of humor. He was a Moravian missioner who, since about 1760, had been, off and on for sixty years, in live contact with Indians, mainly Delaware, but also with their Algonkian cousins, the Shawnee, in the Ohio country. He credited them with being "ingenious in making satirical observations, which though they create laughter, do not, or but seldom give offense." In addition, he stated that "genuine wit, which one would hardly expect to find in a savage people, is not infrequent among them," citing, moreover, an excellent example for it (Heckewelder, 1881: 103–104).

All this considered, it appears reasonable that, in 1749, those western Shawnee near the Kanawha mouth, although earnestly bent upon maintaining their recent settlement area along the river, were even more inclined to smile at the ludicrous ceremonial of Céloron and his French companions than was the British colonial government. The chances are that the Shawnee, when asked by the visitors what they called that river, sternly answered, "*Činootahišiθâ.*" Indian sense of humor had found the proper reply for the pale-faces: "He, the Shawnee, is guarding that which is his"; a political declaration rather than the river name for which it passed. Carefully written down according to French phonology, it was inscribed on Céloron's lead plate as '*la Rivière Chinodahichetha.*

In conclusion, an epilogue of a sort is permitted. There is no evidence to show that bands of western Shawnee have ever crossed the Great Kanawha on an eastweard migration. Later events, though, make it all the more clear that the eastern and western Shawnee, when united, since the 1750's, in their new territory along the Scioto and northwest of it, had formed a mighty bulwark against white encroachments of any kind. More than three decades after Céloron's visit to the Great Kanawha in Virginia, they still proved in dead earnest about their political credo as they had once professed it to the Frenchman in a half-humorous vein: *Činootahišiθâ*, 'he, the Shawnee, is guarding that which is his.' The Shawnee nation and its leader, Great Chief Cornstalk, were fiercely determined to defend at all cost their old east boundary south of the Ohio against the land-hungry Virginians, the Great Kanawha River. They felt strong and were full of hope to succeed. In 1774, the ominous year of Lord Dunmore's War, Chief Cornstalk, equally outstanding as a political and a military leader, came south from the Scioto and across the Ohio with about a thousand warriors. Throughout an entire day, they fought a battle, finally lost, against 1,100 Virginians under Col. Lewis, a lieutenant of the Earl of Dunmore, on the flats between the Great Kanawha in the east and the Ohio in the north, near Point Pleasant. While the Shawnee withdrew to the Scioto, Col. Lewis, after his costly victory, marched to the Muskingum and destroyed the Shawnee settlements at Wakatomika, near present Dresden, Ohio. Lord Dunmore's treaty with Chief Cornstalk put an end to the war and, lastingly, to all Shawnee aspirations south of the Ohio. Although Cornstalk conscientiously adhered to the treaty, he was assassinated by Virginians in 1777 (Hodge, 1907, 1910: 350).

In 1774, when Shawnee war captain under Chief Cornstalk, Catahecassa presumably was in his middle thirties (ibid.: 212; Beckner, 1932: 364; 379). Eventually, he himself was made Great Chief and later led his warriors against U.S. Generals Harmar and St. Clair. After Anthony Wayne's final victory and treaty in 1795, Catahecassa, realizing the hopelessness of the Indian cause against the Whites, definitely laid down the battle-axe. As a wise ruler of his Shawnee, he died in 1831, at Wapakoneta, in Ohio, deeply respected by Indians and Whites (ibid.: 212).

About not quite a century before, *Eskippakithiki*, where he had been born during the sojourn of a hopeful west-Shawnee migrating band, lay in the middle of an unclaimed territory which only much later was named 'Kentucky.' In 1831, when he died, a frustrated old Indian, Kentucky and Ohio had long been states of the Union. Denizens from a foreign world had ruthlessly stepped over him and his people.

The sad migrations of the Shawnee and other Indians from east to west, such as inevitably followed, belong to the less glorious features of American history.

SUMMARY

While the northward migration of the *eastern* Shawnee from Georgia through the American east, which started about 1710, took place in the full light of the White Man's history, very little had been known about the simultaneous wanderings of

the *western* half of the Shawnee nation from the Cumberland river eastward through the wilderness later called 'Kentucky.'

Not until quite recently could a few Kentucky neighborhood names be identified by me as unmistakably Shawnee. Their semantic analysis, in conjunction with historic clues, one of them from West Virginia, led to the inference that the localities, thus named, and their geographic sequence, from west to east throughout Kentucky, might be marking the hitherto unknown route of the western Shawnee's migration south of the Ohio.

My opinion was further strengthened by the fact that, in the past, prehistoric sites, most of them certainly, and others probably, of the Fort Ancient culture type, had been found near these places, in both Kentucky and West Virginia. It suggests that, at roughly 1600, the same route, along the same places, had been traveled by the Shawnee, on their east-west migration to their historic territories on the Cumberland and in Georgia.

My sincere thanks go to Professor Thomas P. Field, of the Department of Geography in the University of Kentucky, at Lexington, Ky., for his untiring cooperation. Not only did Dr. Field's list of Indian names in Kentucky spark off this research, but Dr. Field, an expert cartographer, also has designed and provided the figure which accompanies these pages. Further, to Dr. William S. Webb, emerited Professor in the Department of Archaeology and Anthropology, in the University of Kentucky, at Lexington, Ky., for his kind and expert help in Kentucky archaeology. And, last but by no means least, to Mr. Raymond S. Baby, Curator of Archaeology, in the Ohio State Museum, at Columbus, O., for his friendly advice in things archaeological.

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A KINETIC TREATMENT OF PURINE SYNTHESIS

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The biosynthesis of purines in pigeon liver homogenates has been very cleverly and carefully worked out by Greenberg (1951). However, it is felt that the kinetics of this mechanism are of equal importance, but up to date they have not been investigated. It is the purpose of this communication to explain quantitatively the following reaction sequence:

$$CO_2 + 3NH_3 + \text{glycine} + \text{"formate"} + \text{ribose-1-phosphate} \longrightarrow \text{inosine-5-phosphate} \xrightarrow{-H_3PO_4} \text{inosine} \xrightarrow{+H_3PO_4} \text{hypoxanthine} + \text{ribose-1-phosphate.}$$

If the reaction is followed by the use of C^{14}-formate, the kinetics of the C^{14} transfer can be represented very simply, that is,

$$A \xrightarrow{k_1} B \begin{matrix} \xrightarrow{k_2} C \\ \xrightarrow{k_3} D \end{matrix}$$

where A = formate (C^{14})
B = I M P-5 (inosine-5-phosphate)
C = HX (hypoxanthine)
D = inosine

The differential equations for the C^{14} transfer are:

$$\frac{dA}{dt} = -k_1A \tag{1}$$

$$\frac{dB}{dt} = k_1A - k_4B \qquad (k_4 = k_2 + k_3) \tag{2}$$

$$\frac{dC}{dt} = k_2B \tag{3}$$

$$\text{and } \frac{dD}{dt} = k_3B \tag{4}$$

The solutions of the equations can be given as follows:

$$A = A_0e^{-k_1t} \tag{1a}$$

$$B = \frac{A_0k_1}{k_4 - k_1}\left[e^{-k_1t} - e^{-k_4t}\right] \tag{2a}$$

$$C = \frac{A_0k_2}{k_4}\left[1 + \left(\frac{1}{k_4 - k_1}\right)\left(k_1e^{-k_4t} - k_4e^{-k_1t}\right)\right] \tag{3a}$$

$$D = \frac{A_0k_3}{k_4}\left[1 + \left(\frac{1}{k_4 - k_1}\right)\left(k_1e^{-k_4t} - k_4e^{-k_1t}\right)\right] \tag{4a}$$

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In figure 1, the analytical solution is compared with the experimental results. The curves were calculated from the following rate constants:

$k_1 = 7.102 \times 10^{-2}$ min^{-1}
$k_2 = 1.048 \times 10^{-2}$ min^{-1}
$k_3 = 6.288 \times 10^{-2}$ min^{-1}
$k_4 = 7.336 \times 10^{-2}$ min^{-1}
$A_0 = 21.0 \times 10^{+3}$ counts per min per fraction per vessel.

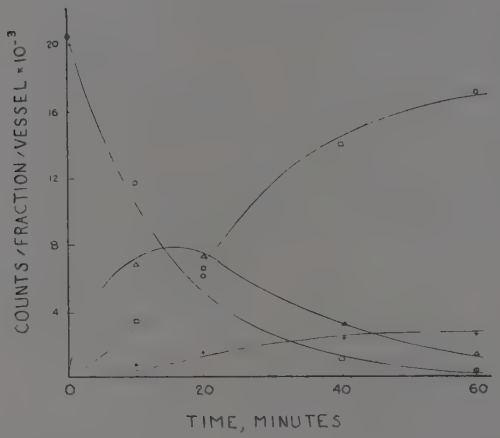

FIGURE 1. Theoretical curves for: o formate; △ IMP–5; □ HX; + inosine.

The agreement appears satisfactory. Further experimental work on this problem will deal with evaluation of the free energy, enthalpy and entropy of activation. Data of this nature for complex reactions are conspicuously missing from the literature.

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FIELD PROCESSES IN SPACE

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More than two thousand years ago Democritus said, "In reality there are atoms and the void." Philosophers from that day to the present have been inclined to follow his lead; they have usually denied to space any semblance of physical properties, any attributes beyond a mere emptiness, a mere "void."

Such a philosophy has never proved adequate. We may refrain from assigning physical properities to space, but it has still been necessary to assign to it abstract mathematical properties, in increasing number and complexity. The geometry of Euclid presupposes a measure of length, valid beyond the boundaries of solid matter, capable of extension to the space outside. More general geometries require a similar supposition if they are to have useful physical application.

We assign coordinates, measures of length and of time, but this is still not enough. In addition we have found it necessary to associate various potentials with these coordinates, the gravitational potentials of Laplace and Poisson, the electromagnetic potentials of Maxwell. These potentials are quantities whose significance is localized, quantities associated with the region of the space and time coordinates to which they are assigned. We can hardly avoid the implication that they are associated with some aspects of a physical process in space.

An important step away from the concept of space as a void was the development of the traditional "ether" concept. This concept sought to describe field phenomena in essentially static terms, in terms of strains and stresses bearing some analogy to the familiar properties of matter. Quantum theory has made it obvious that such a picture is inadequate, that the fundamental structure of nature must be formulated in dynamic terms, in terms of energy, action, and waves. It is quantum theory which provides a clue to the next step.

If we are to apply a quantum viewpoint consistently, we must certainly assign quantum attributes, not only to the structure of matter, but also to processes in space outside of matter. Dirac was perhaps among the first to recognize that space must possess properties beyond those of the traditional ether, basing his inference on profound mathematical considerations. Such an approach unfortunately does not encourage attempts at interpretation; we need a more physical approach if we are to break the grip of ancient philosophies.

Field phenomena can be regarded as representing aspects of an energy pattern in space. Such a view follows naturally from ideas of Maxwell, Poincare, Planck, and many others. It is the one view which assigns a simple, understandable physical significance to field processes; there appear to be no specific objections to it.

The usual descriptions of field phenomena require us to assign quantities whose significance is localized. Still, nothing in the manner of derivation and definition of these quantities demands that they retain significance for regions indefinitely small. Potentials are mathematically continuous functions, but there is no need to regard them as associated with a physically continuous structure.

Field quantities serve to express resultant energy differences directly, without requiring a formulation of small scale structure. Field phenomena at the ordinary scale of magnitude are concerned only with such resultant energy differences and energy changes. These phenomena can give no indication of the presence of any uniformly distributed energy in space; they give no information regarding the density or small scale structure of such energy.

The energy densities associated with field quantities are small. It is usually tacitly assumed that apart from observable fields space is quite empty; the energy density is zero. Such an assumption is entirely arbitrary; we cannot infer the

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actual energy density from these observable fields. Rather, we are free to assign to so-called empty space an energy density which fits in best with quantum processes; this is our only clue to the actual energy density in space. Densities traditionally associated with the "ether" concept are totally inadequate here.

Discontinuity factors form an intrinsic part of this energy background, playing as vital a role there as in the structure of matter. Such factors should not be thought of as a contradiction of classical theories; they are the expression of an essential limitation. The quantum and the Comptom wave length determine an energy pattern of high density.

The interaction of this energy background with small scale processes provides a physical basis for the familiar "uncertainty principle," while small modifications in the field background account for the usual field phenomena. Gravitation and electromagnetism represent modifications of one basic field structure. These concepts serve to express energy differences at the ordinary scale of magnitude, but they do not provide a description of the small scale structure of nature; small scale forces are more potent.

We have ample reason to abandon the concept of an empty space, and substitute a space filled with such an energy background. In regions where this structure is completely uniform, it will show no observable effects at the ordinary scale of magnitude; its net interaction is zero. Observable field effects imply resultant energy differences, which are associated with small modifications of this uniform structure. Where the uniformity of the field background is disturbed, resultant forces appear which tend to restore the normal uniformity and symmetry of this background.

Energy differences associated with field processes in space fall into three simple categories. An interaction with the structure of matter along radial lines may modify the energy of linear motion along one line in space. This field pattern is represented by the gradient of a scalar potential, and constitutes an electric field; the "sources" are referred to as electric "charges."

Similarly, we may have modifications of the field energy around some line in space. This modification of the energy of rotational motion, represented by the curl of a vector potential, constitutes a magnetic field. Its orgin may be associated with the motion of electric charges, or with "spin" energy at any order of magnitude. A magnetic field is *not* a vector field; it is a tensor of the second rank. The use of a vector to represent such a field is a practical simplification which may suggest false analogies with electric field structure, a point often overlooked in textbooks.

The third type of field effect is associated with differences in total density of our field pattern; such differences constitute gravitation. A gravitational field is usually represented adequately in terms of a simple scalar potential, but the small scale processes are here more complex, and a more detailed interpretation may be needed to correlate associated phenomena.

In the electromagnetic field there is in general no specific relation between the source "charges" and their intrinsic energy or mass, so the value of "charge" is assigned without reference to any associated mass. In the gravitational field, on the other hand, no measurable difference in the gravitational acceleration of different substances has been established experimentally, so it has been customary to assume a complete equivalence of gravitational and inertial mass. We can maintain a correlation with electromagnetic field structure if we use a formulation which does not depend on such an assumption. This is easily done.

We can simply start out as with other field processes. For the interaction of two entities we write $F = Q_1Q_2\ r^2$. As in the electromagnetic field, this is regarded as strictly applicable only to stationary states, but its purpose is to assign to each entity a quantity, Q, characteristic of that entity; this quantity serves as a measure of its interaction with the surrounding region. Though it is usually referred to

as a "gravitational mass," this quantity is *not* in mass units. Rather, it corresponds dimensionally to electrostatic charge and magnetic pole strength. Such assigned quantities provide us with a means of describing the gravitational field in essentially the same way as the electromagnetic field.

Newton's law in its usual form implies the additional assumption that these assigned quantities, Q, are exactly proportional to the masses, m; i.e., $Q = Km$, where K is a dimensional constant determined experimentally. The expression $F = Q_1Q_2/r^2$ becomes identical with Newton's law by taking $g = K^2$.

More generally, we express our distribution pattern by assigning potentials distributed in space and time. The source quantities then serve simply as labels which determine these potentials. For gravitation, as for other field processes, we may define our potential as a summation of (Q/r), and determine the force acting on any entity by multiplying its assigned value of Q by the potential gradient in its region. No constant appears in this relation; a constant appears only in the relation between Q and m. To the extent that this constant is uniform for all accumulations of matter, the formulation remains equivalent to Newton's law.

The potential so defined has the dimensional status $(\text{force})^{\frac{1}{2}}$, the same as the basic potentials of the electromagnetic field (Holm, 1959). We thus parallel the usual formulation of electrostatic and magnetic fields. Even though the physical pattern of our field energy is different in all three cases, we can still use units which are the same dimensionally and in magnitude. This is possible because we are in no way describing the detailed small scale structure of field processes; our field quantities simply express resultant energy differences directly. They have no more basic significance.

In describing gravitational interaction, one application of K is concerned with the interaction between the source masses and the surrounding field while the second is concerned with the interaction between the field and the entity acted upon. These are distinct physical processes, separated in space and time. If we assume a uniform value of K, the two constants can of course be combined without affecting the mathematical results, but we must recognize that this is not in accord with an objective interpretation of gravitation as a sequence of physical processes. Any deviation from a uniform value of K at once requires us to split the constant, g, and assign a proper constant to each entity. We are prepared for this eventuality if we parallel the formulation of the electromagnetic field; we can pave the way for a closer coordination of all field processes.

Such a formulation is not too unfamiliar though its basis is usually not stated explicitly. The gravitational Q associated with a one-gram mass is equal to $K = g^{\frac{1}{2}}$, so we require a mass of about 3872 grams to produce unit potential gradient at unit radius. This is the unit of Q commonly referred to as a "gravitational unit of mass." The exact relation between Q and m is the value of K for the substance considered.

Actually only one element, hydrogen, with its atomic weight of 1.008, can be expected to show a significant deviation in its gravitational acceleration. Since hydrogen appears in combination with a variety of elements, it is entirely feasible to make gravitational experiments comparing such substances with others. Apparently no such experiments have ever been made. We need a higher order of precision to compare substances which do not contain hydrogen.

The presence of a basic field structure in space implies one very important consequence. It obviously restricts the generality of any "relativity" principle, making it necessary to assign a more specific interpretation to the Lorentz transformation. This transformation law has a direct and vital physical significance entirely apart from the abstract and mystical philosophy which has come to surround it.

The mathematical basis of the law is no mystery. It can be correlated with understandable physical factors. This means that we must coordinate our mathematical reasoning with attributes of specific physical meaning.

Mathematical methods of reasoning have proved so useful that we may fail to recognize the limitations which surround such methods. Modern physics has largely substituted a mysticism of equations for the mysticism of numbers of the ancient Pythagoreans. It behooves us to examine the reasons for the success of such a philosophy, so we may remain equally aware of its limitations.

We are able to set up physical laws and physical equations only because there exists in nature a degree of uniformity, a degree of consistency. If this were not so, if nature were completely haphazard and unpredictable, there would be no such things as physical laws.

Sometimes the degree of uniformity and consistency is only approximate, as in the biological sciences, and we must rely largely on descriptive names and classifications to express our knowledge. In other areas, the degree of consistency may exceed the degree of accuracy of our observations and measurements, so we are able to set up valid general physical laws. Some such laws may be valid far beyond the order of accuracy of our observations, so we tend to overlook the fact that we are still dealing with a degree of uniformity, a degree of consistency. The fundamental things in physics are not equations, but are rather the uniformities and consistencies which underlie them. Equations are a brief and convenient way of expressing these consistencies, but in the ultimate the equations may not be described as "true," only as adequate or inadequate to any given situation.

The inverse square law serves as an excellent example here; it leads in simple steps to more general laws. This law is in essence simply a geometrical distribution pattern, aptly symbolized by the traditional "lines of force" concept. Physical processes in space conform to this law subject to various limitations. This becomes understandable if we recognize the law, not just as an equation, but rather as a specific type of uniformity.

Field phenomena at the ordinary scale of magnitude all show this simple symmetrical distribution for stationary states. The law represents a distribution pattern in space alone, so it obviously is not adequate for rapidly changing situations where time derivatives become important. Thus, in electromagnetic theory we substitute a more general "equation of propagation."

The electromagnetic field is the domain of a scalar and a vector potential, both of which satisfy equations of propagation. These equations may be regarded as the fundamental equations of the electromagnetic field. Thus, in place of $\nabla^2 P = 0$, we have $\nabla^2 P - \partial^2 P / \partial (ct)^2 = 0$; in place of a simple spatial symmetry we have a specific type of space-time symmetry, a symmetry deriving directly from the propagation process.

It is this type of symmetry which appears in the Lorentz transformation. This transformation law was derived by Lorentz initially on the basis of the electromagnetic field equations; Einstein gave it a more general application. The law takes its form from the equations of propagation of the electromagnetic field, the familiar "wave equations." The denominator of these equations forms the invariant function of the coordinates which is the basis of the Lorentz transformation.

The Lorentz transformation implies the presence of propagation in physical processes in general. We in effect apply the pattern of the equation of propagation to internal mass-energy structure. The fundamental physical fact is the presence of an intrinsic velocity, c, associated, not only with all forms of energy in space, but also with the internal energy of matter. This is the physical basis for the mass-energy relationship $\text{Energy} = mc^2$.

Relativity theory takes the velocity of light specifically as a fundamental thing which does not change, and then without apparent logical connection proceeds to incorporate this velocity in equations that have nothing to do with the propagation of light. We bridge this gap if we regard the velocity, c, as a basic velocity associated with energy in general, an intrinsic velocity in physical processes. This

gives us a more fundamental basis for the continuum of special relativity than the mere transmission of a light signal. We can accept the usefulness of the equations of relativity and still recognize the existence of limits to the relativity principle.

The relativity viewpoint is one of the type of assumptions known as negative postulates, or "postulates of impotence." Such postulates form a necessary and useful part of physics though they are not always stated in the most appropriate language. In abstract mathematics we may be entitled to say, "It is impossible to . . ."; physics calls for more modest statements. Postulates of this type are essentially a simplifying procedure, a process of omitting factors which do not play a measurable part in the experiments considered. We can always conceive the possibility that such factors will play a measurable part in other future experiments, so we can never regard such postulates as ultimate or final truths.

We cannot of course return to Newton's concepts of "absolute space" and "absolute time"; the actual situation is far more complex. A single primary coordinate system cannot form an adequate background for all purposes. We must recognize local variations and restrictions. The general field pattern is modified by the presence and motion of matter. Our choice of coordinates must reflect this; it cannot be made completely arbitrary.

Relativity speaks of observers moving with different velocities. All *actual* observers are effectively limited to one velocity, that of the earth's surface; we have no cognizance of observers moving with a substantially different velocity. For experiments at the earth's surface, we choose a primary coordinate system moving with the earth's surface and apply transformed coordinates to a rapidly moving entity. We will need experimental data under a wide variety of conditions, at high velocities and at a distance from the earth's surface, before we can develop more complete rules for choosing our coordinate systems and specifying their limitations. Detailed mathematical interpretation must await further knowledge, but the concept of "lines of symmetry" can serve as a useful descriptive basis (Holm, 1953).

It is not possible to maintain relativity as a *principle* since it leads to a variety of paradoxes and contradictions. Such paradoxes seem too abstract to be generally convincing; we need a more direct and satisfying proof of the limitations of the relativity principle. Space rocket experiments should soon make this possible.

Newton's laws of motion implied a simple relativity, valid for low velocities but not strictly true. To deal with high velocities we need the Lorentz transformation. It remains a fundamental physical law, but its exact range of validity is still to be determined.

The Lorentz transformation is inherently coordinated with the electromagnetic field equations; it is the gravitational field which requires further consideration. Changes in gravitational fields usually take place much too slowly to make time derivatives of the potentials directly significant; this aspect of propagation becomes important only at very great distances. We are dealing with energy densities, so a scalar potential is generally adequate. There remains one situation where we find it necessary to go beyond Newton's law.

Mass was traditionally regarded as a simple scalar constant assigned to any particular portion of matter. Today we know that such a concept is valid only at low velocities. For a rapidly moving entity, mass becomes a tensor subject to the Lorentz transformation.

The Lorentz transformation can be applied directly to determine the precession of a planet, as Birkhoff (1950) has shown. We need not assume the general validity of the relativity principle; we can avoid the even more abstract assumptions of the general relativity theory.

The general relativity theory still reduces its conclusions to the concept of an orbit and its precession. The word "orbit" in itself defines a coordinate system since it implies the attributes of size, shape, and position. When we speak of the

precession of an orbit we necessarily infer a precisely specified coordinate system. In contradistinction to the relativity viewpoint, such a specific coordinate system seems peculiarly suited to the description of planetary motion; the orbit appears as a path through the field.

The concept of a basic field structure in space permits us to interpret photons as simply small increments of energy superimposed on this structure, much as signals are superimposed on a carrier wave. The field structure can transmit such individual pulses of energy, or more complex superimposed wave forms. We reconcile at once the "wave" and "particle" attributes of radiation; light manifests wave attributes simply because it is superimposed on an existing wave pattern. The physical property which distinguishes the individual photon is its energy or momentum. Wave length is *not* an intrinsic property of the individual photon; it appears only as a statistical distribution of photons in space. The field background plays an essential role in creating such a probability pattern. There is no directly associated frequency; the time of emission of the photons may be quite random.

The most elementary property of such a statistical distribution is the inverse relation between the size of these energy increments and the resultant wave length. If we compare these wave lengths with the basic Compton wave length, we see that visible light consists of very small energy increments, only a few parts per million. Small as these increments are, they still produce some specific effects. The eye, for example, responds directly to the energy impact of the photons. It has no mechanism for forming or recognizing wave lengths; the same is true of the photographic plate.

With larger increments, individual effects are more readily identifiable, "particle" attributes become more prominent. Smaller increments are less likely to show identifiable individual effects, but they can form part of a larger scale pattern. When we produce waves by electromagnetic means, the quantum discontinuity of the field becomes quite unimportant. The source introduces regularity in both time and space; frequency has a direct physical significance. We deal directly with this larger scale wave pattern.

Only the transverse aspect of radiation appears experimentally; the absence of an accompanying longitudinal wave has no adequate explanation in classical wave theory. We face no such problem here; the longitudinal wave pattern simply remains uniform in any region of space. Our field structure can transmit small energy increments for enormous distances without substantial attenuation.

An attenuation, a gradual loss of energy by individual photons, is certainly conceivable; the remarkable aspect is its smallness. We surely need not picture field processes as taking place in a structure of infinite rigidity. We have no very positive means of distinguishing such a factor from a possible expansion, but it can explain Olber's paradox and Hubble's limit without the need for assuming an expansion. The existence of a basic field structure in space requires a radical modification of expansion ideas.

The designation of h, rather than hc as the quantum constant, is probably a serious error. No experiment measures a frequency associated with visible light, or radiation of higher energy content. We have good reason to believe that such a frequency does not exist. Where we introduce a frequency directly, as in waves produced by electromagnetic means, the quantum constant loses its significance. The measured quantity associated with visible light is a statistical distribution of photons in space, a length, not a frequency; it is related to hc, not to h.

The distinction becomes increasingly important when we examine its more fundamental implications. To use hc consistently in place of h will generally necessitate multiplying momentum by c also, giving us a directed or vector energy, expressed in energy units. Conservation of momentum then appears as a special aspect of the principle of conservation of energy, just as the conservation of mass is a special aspect of the same principle.

Using values given by the Lorentz transformation, we see that the momentum-energy of a "particle" is related to its mass-energy through its relative velocity, $B = v/c$; i.e.,

$$\text{Momentum} \times c = \text{Energy} \times B.$$

In the case of a photon, energy and momentum are related by the constant factor, c:

$$\text{Momentum} \times c = mc^2 = \text{Energy}.$$

There is thus no essential physical distinction between the two concepts for a photon, or for field energy in the fundamental sense. Energy and momentum merge in one basic concept of field energy. The customary scalar energy function is one aspect of this concept; momentum is another aspect, the directional aspect or component of our energy pattern.

The three concepts mass, energy, and momentum differ in pattern and context but are united in their fundamental significance. Their reduction to a unified common basis is a necessary prerequisite to a consistent interpretation of physics. Such a simplification in our fundamental concepts permits one conservation law to serve as a basis for all of physics.

Fundamental Constants

The basic field structure depends on:
The quantum, $hc = 1.986 \times 10^{-16}$ erg • cm.
The Compton wave length, $\lambda = 2.426 \times 10^{-10}$ cm.
We derive a density, $hc/\lambda^4 = 5.73 \times 10^{22}$ erg/cm^3 = 64 gm/cm^3.

Electron structure depends on:
The angular quantum, $hc/2\pi = 3.160 \times 10^{-17}$ erg • cm.
An effective radius of action, $r = \lambda/2\pi = 3.861 \times 10^{-11}$ cm.
These determine a mass-energy, $mc^2 = hc/2\pi r = 8.185 \times 10^{-7}$ erg.

The electrostatic field energy $e^2/2r$ is only 1/273 of the electron's mass-energy.

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Living Resources of the Sea. *Lionel A. Walford.* Ronald Press Co. xv+321 pp. $6.00.

This book was written by assignment. The project was specifically to determine how the harvest of sea fisheries could be substantially increased for the benefit of humanity, a goal set by the Conservation Foundation. The author is Chief of the Branch of Fishery Biology of the U. S. Fish and Wildlife Service and therefore able to obtain materials and perspectives adequate for the assignment.

Walford fulfilled his assignment by presenting the facts about "The Marine Wilderness" and discussing "The Resources of the Sea" in very readable manner, with adequate tables of data and maps, and then presented his conclusions in a final chapter entitled "Looking Forward." Briefly he states that there is no reason to believe that very much more can be added to present harvests with present antiquated methods and philosophies of using the resources of the sea, that the full use of such resources depends on a web of knowledge, that there is no simple, direct short cut to a full understanding of the proper uses of the sea and so "If we really desire to exploit the sea fully, if it is knowledge that we need to accomplish that purpose—and that is the theme of this book—then we had better make the necessary costly investment and put full effort into the job of acquiring that knowledge."

The author states the need for scientists, suggesting the establishment of teaching and research centers in regions of critical need, with concentration of their efforts at a thorough taxonomic and quantitative survey of the biological resources of each region. This logical deduction is not exactly new!

THOMAS H. LANGLOIS

A REVIEW OF SOME PROBLEMS IN THE STUDY OF BIRD MIGRATION

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GENERAL CONSIDERATIONS

Field observations of migration are difficult to interpret as well as difficult to make. For example, the correct interpretation of the numbers of birds seen in migration may be in doubt. The number of birds observed is often assumed to be directly proportional to the magnitude of migration, but even this basic assumption may be questioned. Crissey (1955) estimates that not over 25,000 Black Ducks are in New York at a given time, yet over one-half million birds probably move throughout that state. Snow (1953) observed Chaffinches appearing out of a clear sky and commented, ". . . with this species therefore, perhaps more than any other, it is not at all certain how far the observed migration represents any considerable portion of the total migration that is going on." Lack and Lack (1933) noted differences in the numbers of birds moving through varying topographical situations of the same general area. Newman (1952) points out the confusing situation when a number of birds interrupting migration and flitting about in an area appear to the observer as many individuals moving through the area. Moreau (1953) calculates the large number of birds an observer could see in the Mediterranean area as opposed to those actually seen and concludes, "Such a realization helps one's sense of proportion and a realization of how great a percentage of migrants must pass undetected." The foregoing citations indicate that a large part of migration may be unobserved. Compared to the total population, fluctuations in numbers of observed birds by chance may be relatively insignificant.

A further difficulty lies in obtaining accurate counts of those birds potentially within the observers view. Lowery and Newman (1955) sum this up by stating, "A considerable portion of diurnal migratory activity doubtless takes place through the screening foliage of the trees, where the presence of non-migrating birds of migratory species adds to the observer's confusion. Under these conditions, accurate space-defined sampling of the rate and frequency of passage is next to impossible." Lowery and Newman's various publications on nocturnal bird migration (Lowery, 1951; Newman, 1952; Lowery and Newman, 1955) describe an attempt to solve the problem of sampling bird migration, for as they conclude, "The analysis of Lunar flight co-ordinates derives its research status from the fact that it permits more precise numerical measurements of migration as a mass movement than does any other method applicable either by night or by day." The lunar method is not without its own problems, and has one special difficulty in that species cannot be identified (Farner, 1952).

If observed numbers of birds were always more-or-less directly proportional to the magnitude of migration, then the effects of weather on migration could be easily ascertained. The preceding discussion suggests that the relations between observed birds and the true extent of migration is not entirely clear, and therefore the significance of weather variables on the total flight may not be as obvious as thought. In addition to this problem, a critical approach to studies of migration should consider the following:

1. The proportion of a migratory flight affected by weather may vary with different weather conditions. Many correlations between influxes of birds and weather have been noted and the numerous papers dealing with this need not be cited. Obviously, there is a relation between weather and migration, but there

are apparently no data on the porportion of the birds in flight that are influenced by given weather conditions.

2. Physiology of the migratory population may change from one observation period to the next. Studies on fat deposition (reviewed by Farner, 1955) indicate remarkable physiological activity in migrants, and suggest increased metabolism and rapid food utilization. All of these are situations of importance in establishing various levels of behavorial motivation which may change rapidly with, for example, the extent of food supply, the duration and time of previous feeding, fatigue, and the like.

Seldom are weather conditions repeated in an interval of time that permit exclusion of consideration of physiological changes in the birds. For example, after the passage of one cold front, and a subsequent influx of birds, a sufficient period of stable weather may ensue to permit such physiological changes in the migratory population that the arrival of a second cold front impinges on a physiologically changed bird. Consequently differing proportions of the population may respond to the two cold fronts. The frustration of the observer is apparent when confronted with the possibility that physiological changes in individual birds may motivate different responses to weather variables at different times and thus changing segments of the migratory population may be affected in different ways at different times!

3. When birds are seen, does this represent a migratory *movement* or a *cessation* of migration? Lowery (1945) and Williams (1945) give some examples of cessation of migration during inclement weather. Some or many of the birds seen might, therefore, be those temporarily non-migratory. Extending this line of rationalization, might there not be times when the "success" of migration is inverse to the numbers of birds observed?

4. Does an influx of birds represent a mass movement, and if so, are the accompanying weather variables the significant stimuli? One problem in analyzing weather data has been mentioned by Farner (1950). "Actually, however, such observations do not necessarily indicate whether migration would or would not have occurred in the absence of the external stimulus." Unfortunately, weather conditions do not always duplicate themselves in a time sequence condusive to good experimental design or statistical treatment. Despite the wishes of an observer, cold fronts may not occur frequently, nor may successive fronts duplicate themselves with respect to wind velocity, temperature, cloud cover, and so forth. Even slight changes in the structure of a front may significantly influence the proportion of the flight observed. Until sufficient data are available on the limits of environmental influence on migrants, this point must be kept in mind.

THE USE OF INFLUX AND DEPARTURE DATA

Some of the foregoing difficulties may be overcome by the judicious use of both influx and departure data. Regardless of what proportion of the population is involved, departure data give clues as to the influence of known environment of those birds under observation. In influx data the consequences of behavior are noted, i.e., appearance of birds, but the initiating environment may lie at a distance. When studying departures the daily behavior and numbers of the birds can be noted and their surrounding environment measured directly. In influx data it is necessary to hypothesize not only what variables were operating, but also the probable locale of activity. With departure data the locale of the start of a flight is known and need not be hypothesized.

If influx data represent cessation of migration, then the hypothesis regarding weather stimuli can be made with considerable justification, for presumably the effective environment is that present at the time of the precipitation of the birds. Many of the papers using influx data, however, are concerned with the *initiation* of flight. Of course, quite reasonable work using influx data can be done by

combining mass observation data with knowledge of probable ranges of birds, what is known in general of the birds behavior, together with previous records, and weather map data.

As an example of the use of influx data, consider the study of fall warbler migration in Lincoln Park, Chicago, Illinois done by Bennett (1952). His data indicated a correlation between high numbers of warblers and cold front passage through the area, and he concluded, "Early cold fronts in late August and early September were always followed by important warbler waves." Bennett (op. cit.) also indicated that birds moving on a NW wind might become concentrated in the Lincoln Park area due to the barrier effect of Lake Michigan. The numbers noted by Bennett thus, could reflect either influx (wave) or a pile up of birds due to the lake barrier. In either case it is difficult to analyze the factors that may have initiated the movement. Was it wind, temperature, cloud cover, and how soon after the front passed did these stimuli become effective? Did all of the birds start from the same place and under the same weather conditions? When did the flight start? In a less obvious fashion all of the warblers in the waves did eventually leave the park area, "Many of the arriving birds must have remained for a considerable period of time departing gradually" (Bennett, op. cit., p. 208). "Under static conditions the birds evidently moved leisurely southward, making many short flights instead of mass movements stimulated by cold fronts" (Bennett, op. cit., p. 216). Study of the circumstances surrounding the departure of these birds should yield considerable information on the influence of weather on migration. Whether a mass flight occurred or not, many birds were stimulated to migrate *out* of Lincoln Park as well as *into* it. An observer using departure data would know the general locale of flight initiation, and could by daily sampling reduce the time error in estimating start of flights, and also could measure weather variables directly.

The use of influx data may lead to unwarranted assumptions regarding the length and magnitude of the flight. Why is the assumption frequently made that the incoming birds have made a long intense flight while the departing birds will make a short leisurely flight? Perhaps lacking the excitement attending a big warbler day, the observer feels the departing birds must be moving leisurely and in short hops. Any wave, nevertheless could be compounded from birds making short hops as well as those making distant flights. Actually, the length of flights is not usually known from either departure or arrival data, and this is a weakness of both methods of study.

Departure data may include observations of birds actually taking flight and the observer here is presented with a rare opportunity to collect the information on initiation of flight. Raynor (1956), Miskimen (1955), Ball (1952), and Lack and Lack (1953) have mentioned such observations. More often, departure data include instances of decreases in bird numbers together with daily records of weather. Dennis (1954) uses departure data in the foregoing manner and notes departure of migrants in April during periods of warm, clear weather, and southwest winds.

ADDITIONAL PROBLEMS

The examination of departure data may result in confirmation of hypotheses now erected from influx data. Usually, however, the use of departure data reveals many problems not readily apparent in influx data. As an example of specific problems encountered, and the use of both arrival and departure data in field research, some limited information may be taken from a study of bird migration at The Ohio State University from 1952 to 1956. Shorebird habitat at O'Shaughnessy Reservoir, Delaware County, Ohio, is limited to newly exposed mudflats, small in area, and separated by expanses of rocky sterile shore. The river above and below the reservoir offered little favorable shorebird habitat, and the nearest

comparable water area was over 10 miles to the northwest. The small number of shorebirds regularly observed in the area, together with the limited habitat available at O'Shaughnessy made possible accurate counts of shorebirds. Individual shorebirds with peculiar water stains could be recognized for a time at least. The presence or absence of a few birds could, therefore, be detected fairly easily because of the limited habitat, small flocks, and, at times, the presence of marked individuals. The weather phenomena most commonly considered in migration studies, i.e., air temperature, light intensity, cloud cover, surface wind velocity, and frontal activity were noted daily at the reservoir. This information plus that available on U. S. weather maps enabled some consideration of the force and extent of weather changes in the area.

In using such data, a decision must be made as to what numerical changes of birds will be considered valid. The numerical loss or gain may not reflect the actual change of birds. Complete population turnover could occur and not be noticed at all if the number of birds remained nearly the same from day to day. Statistical treatment cannot be used to determine significant levels of numerical shifts because of the possibility of this hidden change. The most direct solution is to examine those changes of sufficient quantity as to most reduce the chance of sampling error. Such changes are *known* decreases (or increases), though un-

TABLE 1

Cold front passage and increases in daily counts of Pectoral Sandpipers at O'Shaughnessy Reservoir, Fall 1952

Date of frontal passage	Date of increases of 10 or more birds
August 4–5	August 4–5
August 11–12	August 12–13
August 21–22	August 22–23
September 1–2	no data
September 6–7	no increase
September 19	September 18–19
September 26	no increase
October 1	no increase
October 5	October 5–6
October 10*	October 9–10
no front	October 11–12
October 13	no increase
October 16	October 17–18

*North of area.

doubtedly this treatment *excludes* some changes that did occur. But, if information on causes of known changes can be obtained then the data may be reexamined for less obvious changes. Because of the nature of the small populations and restricted habitat at O'Shaughnessy Reservoir, a deviation of 10 or more sandpipers was selected as a reflection of true population change, and not due to sampling error.

Table 1 summarizes increases in Pectoral Sandpiper population and cold front passage at O'Shaughnessy Reservoir in the fall of 1952. Increases in these birds seem to be associated with the passage of a cold front. This was not the case following the weak frontal passage of September 6–7, or after the active frontal passage of September 15–16. An increase occurred on October 11–12, before, not following cold front passage in the area. In general it appears that something in the fronts may act as a stimulus for Pectoral flight. Acceptance of this hypothesis must depend on knowledge of the weather at the locale of the start of the flight,

and the length of the flight, both of which are unknown quantities in this instance. Did the birds start flight from an unknown locale *after* frontal passage or is the increase observed at O'Shaughnessy just a few birds dropping out of a larger movement *with* the front? Though the arrival of birds may be associated with cold fronts, the increase data do not indicate what kind of association occurred. For example, does flight initiate with or following the front, and if flight initiates after frontal passage, how long after, and do all the birds respond alike? Apparently the increases occurred during or very shortly after frontal passage. The birds may have been moving with the front, or before it and been precipitated by the weather conditions, or they may have dropped in to the reservoir because of fatigue or hunger. Another possibility is that the birds were moving behind the front, over-extended their flight, and consequently were precipitated by weather at the front.

Examinations of the departure data should yield some information on whether or not birds will leave the area before or after cold fronts. Granted that not all departures will be detected by examination of decreases in counts, do those departures that do show up correlate with any weather pattern? When the data

TABLE 2

Decreases in daily counts of Pectoral Sandpipers and weather data, O'Shaughnessy Reservoir, Fall 1952*

Date of decrease	Percent change in cloud cover	Change in air temperature	Change in wind direction	Date of last cold front
August 5–6	25 to 75	67 to 69	SE to NW	August 4–5
August 13–14	100 to 00	64 to 66	NW to SE	August 11–12
August 23–24	00 to 00	75 to 80	N-no change	August 21–22
August 27–28	00 to 50	85 to 75	NE to E	August 21–22
September 19–20	75 to 25	63 to 70	NW to W	September 19
October 7–8	00 to 100	43 to 60	NW to N	October 5
October 18–19	100 to 00	42 to 52	NE to NW	October 16
October 20–21	25 to 00	40 to 38	NW to NW	October 19–20
October 22–23	00 to 00	40 to 52	SW to N	October 19–20

*Data reported are those recorded in the study area at the start of consecutive daily censuses.

on decreases are examined (table 2), there is some correlation apparent between numbers and weather. Comparison of the first and last columns of table 2 suggests that Pectorals left the study area in the clearing weather of a day or two after frontal passage. No decreases were noted preceding frontal passage. Combining arrival and departure data, it seems that birds may be stimulated to migrate after frontal passage, and that some birds may extend their flight into or to the front and then cease flight.

There were increases and decreases in counts that do not correlate with cold front passage (see tables 1 and 2) and there were cold front passages without apparent changes in numbers of birds. In addition, some individual variations in departure were exhibited by three Pectoral Sandpipers recognizable because of peculiar water stains. No other birds with similar staining were seen at the study area, and no dilution was noted in the intensity of the stain during the time that the birds were seen. One such marked bird was observed from October 6 to October 18, during which time one cold front passed, October 13 14. A second bird was noted on October 12 and 13, and not seen after the cold front of October 13 14. A third recognizable bird was noted from October 8 through October 22, during which time three cold fronts passed through the area. These birds appeared

normal, and maintained as much activity as unmarked birds associated with them and presumably were healthy birds, in other words, the length of stop-over did not seem to be influenced by disability. The variable length of stop-over of these birds, and those changes in numbers not associated with cold fronts suggest that not all individuals of a species leave an area at the same time (following frontal passage) and that the length of stop-over varies from individual to individual. Wolfson (1954) noted a variation in length of stop-over with extensive data on White-Throated Sparrows.

O'Shaughnessy Reservoir also served as a stop-over area and wintering grounds for migratory waterfowl. All flocks of ducks on the reservoir could be observed and individuals counted. Black Ducks and Mallards made early morning and evening flights from the reservoir to nearby grain fields, but rested on the water or shores of the reservoir during the middle of the day, and counts of the individuals present could be made at that time. Concurrent studies (Swinebroad, 1956)

TABLE 3

Increases in daily counts of Black Ducks and cold front passage at O'Shaughnessy Reservoir in the Fall of 1952, 1953, 1954

Date of frontal passage	Date of increase
1952	
December 5	December 3–4
no front	December 6–8
December 10	no change
December 18	December 16–18
1953	
December 4	December 4–5
December 12	December 12–13
1954	
December 4	December 3–4
	December 4–5
cold weather	December 6–7
prevails through	December 7–8
December, increase	December 8–9
may reflect freezing	December 8–9
to north	December 9–11

indicated that counts varying 10 percent or less could have been due to sampling error, and consequently only changes of 15 percent or more were selected for analysis. Table 3 presents the increases in Black Ducks and dates of cold front passage.

Several increases in Black Ducks were associated with frontal passage. The increases were noted just before or just after frontal passage. These data suggest that flight may be initiated by factors following a cold front as in the case of Pectoral Sandpipers, and some birds may catch up with or penetrate the front. However, the decrease data on Black Ducks (table 4) show decreases not associated with frontal passage, and furthermore, decreases occurred under a variety of weather conditions, i.e., clearing, clouding, overcast, partly cloudy, and clear days, each with various wind velocities, and temperature changes. Winner (1957) also found no correlation existed between departures and any combination of weather conditions studied. A similar variation in weather during departure period is true for Pectoral Sandpiper data (table 2), though to a lesser degree.

If the study at O'Shaughnessy Reservoir had been concerned only with the influxes of birds, a hypothesis might be erected that variables associated with cold fronts stimulate migration of those species observed. When departure data (decreases) are examined, it is apparant, however, that departures of some birds from the area did take place under a variety of weather conditions and that there were individual differences in reactions to changing weather conditions. The examination of departure data, even of one year and small flocks of birds, necessitates consideration of additional hypotheses to explain the variations observed:

(1) Not all of the individuals of a species reacted the same way at the same time to weather. Whether this is due to physiological state, or to motivational level, or to both, is the subject of proposed research.

TABLE 4

Decreases in daily counts of Black Ducks and weather data, O'Shaughnessy Reservoir, Fall 1952, 1953, 1954*

Date of decrease	Percent change in cloud cover	Change in air temperature	Change in wind direction	Date of last cold front
1952				
October 24–25	00 to 00	50 to 66	W to NE	October 19–20
October 28–29	75 to 75	41 to 32	NW no change	October 27–28
November 3–4	100 to 100	49 to 32	NW to SW	November 2–3
November 14–15	00 to 90	40 to 33	S no change	November 9–10
November 19–20	100 to 25	50 to 49	NW no change	November 19–20
November 29–30	100 to 90	29 to 28	SW to NW	November 26
December 2–3	100 to 100	30 to 28	SE to N	November 26
1953				
November 1–2	00 to 00	65 to 56	SW no change	October 23–24
November 8–9	25 to 100	37 to 40	SW no change	November 3–4
November 14–15	100 to 00	42 to 22	SW no change	November 3–4
December 13–15	90 to 00	43 to 22	SE to SW	December 12–13
December 16–17	50 to 00	22 to 8**	SW to NW	December 16–17
1954				
November 14–15	0 to 0	42 to 36	SE to NE	November 14–15
November 19–21	100 to 100	57 to 41	SW to NW	November 19–21
November 28–29	0 to 100	32 to 42	SW to NW	November 29–30
December 17–20	100 to 100	31 to 37	SE to SW	November 29–30

*Data reported are those recorded at the start of consecutive daily censuses.
**Area freezing over.

(2) Weather stimuli other than that associated with fronts brought about migration.

At any rate, the use of departure data has made possible an examination of the circumstances under which migration was initiated (tables 2 and 4). Even though the exact departure was not noted, daily weather records make possible a fairly reasonable testable hypothesis about the conditions during which the departure must have taken place.

With both the sandpipers and ducks in the foregoing sample, the data presented here are not sufficient to offer any but a point for discussion. Many of the problems arising from the use of arrival and departure data, as discussed previously, remain unsolved. Some indication *is* given by the departure data that appearance of these birds correlated with cold fronts may be due to stimuli inherent in the air mass following the front, rather than in the immediate influence of the front, and the data serve as examples of the approach possible.

Perhaps most important, the examination of departure data has raised questions regarding specific migratory stimuli, the nature of influxes or waves, the distance of flight in relation to influxes, the dynamics of physiology and motivation in migration, and will initiate continuing study on avian biology along channels that may not have been foreseen via the study of influx data alone. If additional information shows a lack of correlation between those weather phenomena commonly measured and departures from a study area, attention will be turned to other environmental stimuli, including, for example, social facilitation, upper air masses, hunger cycles, etc. If additional data do show a better correlation between certain weather phenomena and departures, the data already accumulated may be examined for sampling errors, and experimentation may be directed into the exact nature of these stimuli and their reception by the bird.

The apparent correlations noted between arrivals and frontal passage in the fall and, similarly, that between arrivals and southerly winds in the spring may lead to a feeling of satisfaction in the investigator which is not warranted, and may gloss over actually complex and dynamic processes in bird migration rather than stimulate increasingly critical approaches to the problem. An intense study of both arrival and departures should provide more precise information on significant environmental variables involved in migration and may direct laboratory investigation regarding the development of migratory behavior in the individual and in the group.

SUMMARY

Problems are discussed concerning the interpretation of field data on bird migration. Particular problems noted are (1) the number of birds observed may not reflect the true migration pattern; (2) physiological changes in birds may result in their differing in response to succeeding migratory stimuli; (3) the appearance of birds may reflect a cessation of migration, and (4) statistical treatment of such field data is difficult.

The limitations due to use of only influx data are considered. The additional use of departure data may give more direct evidence as to factors, initiating migration, as weather variables and behavorial changes in the birds may be measured directly and compared with noted decreases in bird populations.

Examples of additional problems met when examining both influx and departure data are given from studies of shorebird and water-fowl migration in Central Ohio.

Consideration of departure data may cast doubt on the conclusions based solely on influx or arrival data, and may lead to new lines of study, and an increasingly critical attitude of the observer toward problems of the study of bird migration.

Note

Recent papers by Lack (see Lack, David. 1959. British Birds 52: 258–267, Ibis 101: 209–234) received too late to be discussed in this paper support some of the general inferences of this manuscript. Radar observation by Lack ". . . confirms that the migration visible by day may be not merely incomplete but also unrepresentative of what is passing overhead." The use of radar, while it entails certain difficulties and has limitations, does provide a method of obtaining masses of arrival and departure data which lend themselves to precise analysis.

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Prehistoric Man. *André Leroi-Gourhan.* Philosophical Library, New York, 1957. 47 photographs, 18 sketches, 120 pp. $4.75.

As a summary of the status of thought *in the early 1950's* on prehistoric man in central Europe, this little book undoubtedly will satisfy some. In light and casual vein, it is written with little attempt at serious scientific discourse. The delightful description of the birth of tools, with many (9) lucid accompanying sketches, and the several ingenious illustrative devices (e.g., photograph of a primitive family in Indo-china above, and below, after sudden disaster, sketch of their bones and artifacts as might appear several millennia hence to the searching archeologist) made reading enjoyable.

It is not certain that translation from the French has helped. In certain passages strata probably should be read for soil, and ape for monkey. Throughout the book caribou certainly was intended, not reindeer (No evidence exists anywhere that these animals were domesticated.). The weak background in geology, particularly in Pleistocene geology, shows clearly, as in the chapter on climate and nature (strata, the glacial periods, and evidence furnished by plants and animals). The erroneous picture of glaciation in Europe, the narrow thinking on the origin of stream terraces, the several untenable statements and the out-dated information, in this day of enlightenment here seems unforgivable. Yet the text on prehistoric man is scrupulously written in an unprejudiced authoritative manner.

SIDNEY E. WHITE

A QUANTITATIVE STUDY OF THE WINTER PLANKTON OF URSCHEL'S QUARRY

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A quantitative study of the plankton populations of Urschel's Quarry was conducted between October, 1958 and February, 1959. This is a relatively shallow limestone quarry, typical of northwestern Ohio, and is located in Bowling Green, Ohio.

In the past there has been much debate over the classification of certain forms which are autotrophic and possess some means of locomotion. For this study, those forms which are autotrophic, the green flagellates, have arbitrarily been classified as phytoplankton while the consumers have been classified as zooplankton.

METHODS

One procedure used to study the distribution of organisms in a body of water requires that the volume of each genus present in a given volume of water be measured. Based upon a review of the literature, two methods from which results may be obtained in volumetric units, the chamber method advocated by Ruttner et al. (1953) and the silk-bolting cloth method of other investigators, were selected as being best suited for use in Urschel's Quarry. The methods were modified slightly, however.

In order to enumerate the plankton by the chamber method, a water sample was shaken vigorously and a subsample of it, 1 cm in depth, was placed in a stender dish. This subsample was then treated with a few drops of either Rohde's fixative or 6–3–1 fixative. However, since the fixatives produced changes in the shape and color of the plankton, it was necessary to examine a sample containing living organisms to see which genera were present.

All the plankton in ten randomly sampled fields of the fixed sample were identified under 450× magnification, counted, and measured with a calibrated Whipple ocular. Next, five fields were examined under low power (100×), and the more common forms were enumerated in a similar manner. After this preliminary count, ten more fields were examined for rarer forms. Since some forms were light and floated, the surface of the sample was also examined for specimens.

The volume of each organism was calculated from the formula for the geometric figure each plankter most nearly resembled and from the measurements which were previously obtained. Appropriate calculations were then made to determine the total volume, in μl/l, of phytoplankton and zooplankton in the water sample.

When the silk-bolting cloth method was used, a 2.5 l sample was filtered through number 25 silk-bolting cloth. The plankton were resuspended in 10 ml of distilled water and were fixed with either of the previously mentioned fixatives. A 1 ml aliquoit was placed in a Sedgwick-Rafter counting chamber and 15 fields, selected at random, were then examined under low power (100×). All the plankton in these fields were identified, counted, and measured. Appropriate calculations were then made to determine the total volume of organisms in a liter of the sample.

The time of day and the depth at which samples were taken were considered important since they might cause variations in the volumes of organisms present in a given quantity of water. Therefore, samples were collected from the surface

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and 3 m in depth at 0830, 1500, and 2100 hours. These samples were collected from the east bank of the quarry with a Kemmerer water sampler. After the ice had formed, samples were taken from the middle of the quarry instead of on the east bank. This enabled the taking of an additional sample from 5 m in depth.

RESULTS

Comparison of methods.—In a comparison of the two methods of sampling, I found that the chamber method yielded the more accurate phytoplankton estimates. In contrast, the silk-bolting cloth method was the superior method for zooplankton analysis.

There was only a very slight loss of phytoplankton in the chamber method. This loss apparently resulted from fragmentation of the plankton. Therefore, this method was used as a control with which the efficiency of the other method was compared.

It was found that, of the phytoplankton under 30 μ in diameter, only 0.47% were retained by the bolting cloth. The retention of some of this small percentage of phytoplankton may be attributed to adhesion of some of the smaller forms to the larger ones which could not pass through the cloth. Of the phytoplankton over 30 μ in diameter, 98% were retained and of the 2% passing through the cloth, none were over 40 μ in diameter.

When the total volumes obtained by both methods were compared, it was found that 9.3% of the phytoplankton were unaccounted for in the bolting cloth method. This apparently resulted from plankton having been trapped and retained by the cloth or fragmented beyond recognition by the pressure used in filtration. The loss was somewhat selective since the smaller organisms were lost in greater amounts. These smaller organisms, principally *Chlorococcum* and diatoms, accounted for 7.6% of the 9.3% lost. The remaining 1.7% was *Pandorina*, which is a considerably larger form.

Another point which might account for differences in the results obtained was the use of magnifications 4.5 times greater in the chamber method than those used in the silk-bolting cloth method. This discrepency in sampling technique had to exist since it is impossible to use higher magnifications with a Sedgwick-Rafter cell. Therefore, smaller species were more easily seen in the stender dishes. Furthermore, since 22 genera were observed in the stender dishes compared to only 16 in the Sedgwick-Rafter cell, it appears that smaller plankton may not have been noticed in the Sedgwick-Rafter cell. In contrast, some of the larger, rarer forms appeared only in concentrated samples. This is of interest in a qualitative study, but for a quantitative study it has little value since the observation of one organism in many fields of a concentrated sample can produce very little change in the total volume of organisms.

In contrast to the phytoplankton, it was found that 99.89% of the zooplankton were retained by the bolting cloth. Only one species, *Halteria grandinella* (Kahl), was found in the filtrate. This organism has a diameter of approximately 25 μ, which allowed it to pass through the cloth. However, not all of these protozoons passed through the cloth. Some adhered to the larger plankton and floating detritus which was retained by the cloth and in others, the equatorial cirri, radiated out from the organism in a manner which probably prevented passage through the holes in the mesh of the cloth.

Thus, net or silk-bolting cloth catches may be used for comparison with other methods in a volumetric study of zooplankton since the volume of organisms passing through the cloth is practically negligible. However, it must not be assumed that all the zooplankton are recovered from the cloth. Some, particularly the smaller ones, become entangled in the mesh and cannot be resuspended. Even though this fault existed when silk-bolting cloth was used, it was found, from 68 samplings, that the volume retained by the cloth exceeded that collected by

the chamber method by 2.7 times. Furthermore, variability was greater in the chamber method. Over the five month period, values ranging from 0 to 188 μl/l were recorded for the stender dishes while the range in the Sedgwick-Rafter cells was from 0 to 93 μl/l.

Several observations have been made concerning the chamber method which might explain the 2.7-fold difference between sampling techniques. First, vigorous shaking of the water sample failed to yield an even distribution of the zooplankton since the larger, stronger swimming forms, such as *Daphnia* and *Cyclops*, swam downward while the subsample was being poured and were not caught in the subsample. Secondly, organisms such as *Bosmina* tended to float on the surface of the water after they had been captured. This effect may have been produced by changes in temperature or pressure which resulted in an impairment of the mechanism controlling the equilibrium of the organism. Finally, as the fixative was added, the organisms swam to the edge of the dish and died. This prevented their being detected since the immersed objective could not be focused on the edge of the dish.

TABLE 1

Classification of the phytoplankton communities of Urschel's Quarry according to the volumertically dominant species

Time interval	Dominant species	Range of plant volume (μl/l)*
Oct. 7–Nov. 16	*Chlorococcum infusionum* Diatom (unidentified)	8–48
Nov. 17–Dec. 17	*Chlorococcum infusionum* Diatom *Pandorina morum*	5–19
Jan. 5–Jan. 12	*Pandorina morum* *Chlamydomonas* sp *Cryptomonas erosa*	2–88
Jan. 19–Feb. 24	*Pandorina morum* *Chlamydomonas* sp. *Cryptomonas erosa* *Asterionella formosa*	1–66

*A μl=10^9 cubic microns.

Phytoplankton.—Since only a few species accounted for the majority of the phytoplankton volume, at any given time, it was possible to classify the communities according to their volumetrically dominant species. These communities are listed in table 1 together with the dates on which they were observed to be dominant. The ranges in volume of the samples taken within these periods are also presented.

With the formation of surface ice, on December 8, the free-floating plankton, *Chlorococcum* and the diatoms, disappeared. These were replaced by a flagellate community composed of *Pandorina morum* (Muell), *Cryptomonas erosa* Ehrenberg, and *Chlamydomonas* sp. The population of greatest density, 88 μl/l, was recorded at this time.

Table 2 shows that there was a steady decline in the *Chlorococcum*-diatom population during the first three months of this survey. This was followed by a threefold increase in the total phytoplankton population as the flagellate community became the major component. Following this initial increase, the population rapidly decreased so that the February population, composed of flagellates and *Asterionella formosa* Hass, was lower than that of any previous month.

Table 2 also shows that during the first three months of the study, slight variations occurred when samples were taken at different hours and when different depths were sampled. This variation probably represented natural variation between samples. Therefore, it appears that no vertical or upward migration occurred during this period.

TABLE 2

The average monthly populations of phytoplankton in relation to time and depth

Month	Time	Avg surface population μl/l	Avg 3 m population μl/l	Avg 5 m population μl/l
Oct.	0830	27.83	25.06	
	2100	25.09	24.32	
Nov.	0830	15.98	14.73	
	2100	15.94	16.01	
Dec.	0830	10.06	9.31	
	2100	7.76	7.90	
Jan.	0830	33.49	10.88	3.34
	1500	21.62	3.51	4.23
	2100	35.17	3.39	3.80
Feb.	0830	5.82	4.69	3.80
	1500	9.13	3.89	2.87
	2100	15.00	5.08	

TABLE 3

Classification of the zooplankton communities of Urschel's Quarry according to the volumetrically dominant species

Time interval	Dominant species	Range of animal volume (μl/l)
Oct. 19–Dec. 8	*Cyclops vernalis* *Keratella cochlearis*	0–90
Dec. 10–Jan. 22	*Cyclops vernalis*	0–93
Jan. 26–Feb. 10	*Cyclops vernalis* *Bosmina coregoni*	0–57
Feb. 11–Feb. 24	*Cyclops vernalis*	0–71

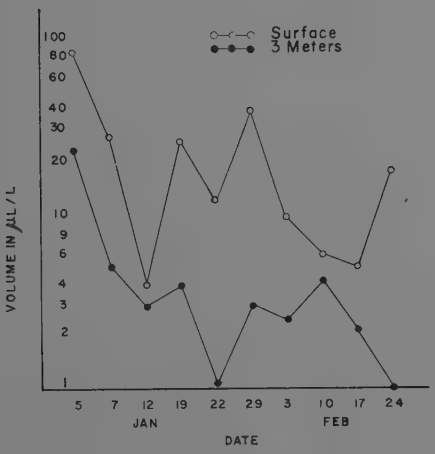
However, in January and February, the majority of the flagellates were found at the surface regardless of the time of sampling. Figure 1 shows approximately a fivefold difference in populations between the surface samples and those taken at 3 m. It should also be noted that, except for the samples of February 10 and February 24, an increase or decrease in the flagellate population at the surface was accompanied by a similar change at the 3-m depth. The variation on these two dates cannot readily be explained. However, on February 24, a tremendous increase in the volume of *Chlamydomonas* occurred at the surface. This was accompanied by a decrease of the other flagellates at all levels. In fact, within one week after this event, *Pandorina* completely disappeared from the samples. These data thus suggest that conditions were better at the surface and that the flagellates usually migrated to this zone.

An unusual distribution of *Asterionella formosa* (fig. 2) was found. This diatom was noted to increase in numbers as the depth increased. Since *Asterionella* has no means of locomotion, it is most likely that a combination of gravity and currents was responsible for its distribution. This haphazard method of distribution appears likely since there was no positive correlation between values obtained at the surface and at 3 m on different sampling dates.

Therefore, it may be stated that, in this study, only those forms which possessed some locomotory powers carried on vertical or upward migration. The rest of the phytoplankton were probably distributed, by physical forces, within the epilimnion.

Zooplankton.—The zooplankton communities may also be characterized by the volumetrically dominant species. Table 3 gives such a classification.

The formation of ice appeared to have a distinct effect on the zooplankton community since the rotifer population, dominated by *Keratella cochlearis* (Gosse), disappeared simultaneously with the freezing of the quarry. This left a copepod community composed of nauplii and adults of *Cyclops vernalis* Fischer. The



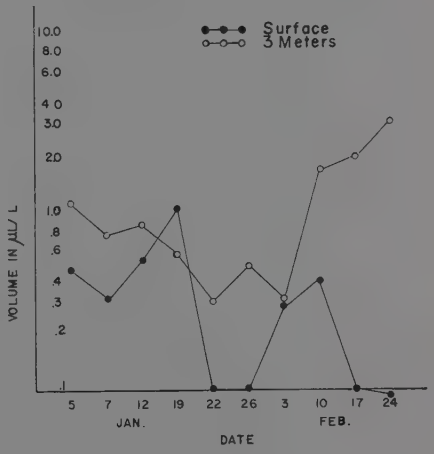


FIGURE 1. (Left) A comparison of the flagellate population at the surface and at a 3-m depth.

FIGURE 2. (Right) A comparison of the *Asterionella formosa* population at the surface and at a 3-m depth.

population of greatest density, 93 µl/l, was recorded during this period. After this period, *Bosmina coregoni* Baird became one of the major components, but this organism disappeared within a short time and once again *Cyclops* was the major component of the fauna.

The volume of zooplankton increased with depth (table 4). Furthermore, no vertical or diurnal migration of the zooplankton was observed.

In a comparison of tables 3 and 4, it may be noted that, except for the month of December, the total zooplankton volume nearly equalled or exceeded the total phytoplankton volume. Measurements of the zooplankton volume from 3 m were not taken during the first three months of this study. If such measurements had been made, the total volume might possibly have been greater and the low December zooplankton volume more than likely would have equalled or exceeded the phytoplankton volume.

From the foregoing information, no conclusion as to the carrying capacity of Urschel's Quarry can be made since only incomplete data concerning the daily utilization of the phytoplankton, detritus and other nutrients by the zooplankton exist. Cladocerans have been observed to have algae and detritus within their digestive tracts and in one instance a cyclops was observed eating a smaller copepod. Therefore, all of these substances must play some part in the maintenance of the zooplankton.

DISCUSSION

Quantitative studies based on the volumes of organisms are not new. Comita and Anderson (1959), Riley (1940), Verduin (1959), and others have advocated this method. However, the majority of limnological investigations have utilized the numbers of plankton per liter as a unit of measurement.

Verduin (1959) states, "The wide variation in volumes of different organisms emphasized the importance of determining volumes instead of reporting populations as numbers of cells per liter." This relationship has been clearly demon-

TABLE 4

The average monthly population of zooplankton in relation to time and depth

Month	Time	Avg surface population μl/l	Avg 3 m population μl/l	Avg 5 m population μl/l
Oct.	0830	17.85		
	2100	33.37		
Nov.	0830	25.92		
	2100	15.37		
Dec.	0830	4.25		
	2100	4.81		
Jan.	0830	21.04	29.89	32.35
	1500	3.71	18.88	14.15
	2100	2.18	41.63	33.41
Feb.	0830	1.07	16.37	12.60
	1500	9.57	43.60	45.99
	2100	37.35	13.97	——

strated in table 5. The smallest phytoplankter, *Chamydomonas* sp. is 1800 times smaller in volume than the largest phytoplankter, *Pandorina morum*. Similarly, the smallest zooplankter, *Halteria grandinella*, is 15,800 times smaller than the largest zooplankter, *Daphnia pulex* de Geer. If these organisms were reported as individuals per liter, they would receive equal weight and thereby obscure the significant difference which they represent as elements in the food chain.

Even with this knowledge, some investigators, who have used volumetric determinations of phytoplankton, have persisted in the utilization of numbers per liter for zooplankton analysis. Davis (1954) believes that irregularity of shape and great variability of size among the individuals of many species prevent the determination of volumes of the various zooplankters. However, if each individual organism is measured carefully, the approximation of the total volume is a more significant figure than the number of individuals per liter.

Verduin (1956) lists literature citations which show that there is a rough inverse correlation between the depth of the epilimnion, or the total depth in unstratified lakes, and the standing crop of autotrophic plants. Since Urschel's Quarry has an average depth of 3 m or a relatively small epilimnion, this might partially

explain the comparatively high value of 88 μl/l of phytoplankton found in this study and the value of 130 μl/l found by Verduin (1959) during the previous year. Both of these high values were obtained from surface samples which were taken through an ice cover. This tends to indicate that the flagellates were capable of maximal utilization of that light which penetrated the ice. This abundance of phytoplankton under the ice has also been confirmed by Smayda (1958) who found an abundant species of *Chlamydomonas* which was capable of phototrophic and chemotrophic assimilation under the ice.

High volumes of zooplankton such as those found in this study have also been found by Anderson, Comita and Engstrom-Heg (1955), who frequently observed a low or inverse correlation between the phytoplankton and zooplankton volumes. Pennak (1949) also reported zooplankton volumes exceeding phytoplankton volumes in six of nine lakes which he studied in Colorado. The data from Urschel's Quarry indicate that an equal or higher volume of animals is not unusual when investigators compare volumes of both phytoplankton and zooplankton instead of comparing volumes of phytoplankton to numbers of zooplankton.

TABLE 5

The range of volumes of organisms frequently found in Urschel's Quarry

Organism	Volume (μ^3)
A. Phytoplankton	
Asterionella formosa (cell)	1,250
Chlamydomonas sp.	36
Chlorococcum infusionum	520–4,160
Cryptomonas erosa	900–1,728
Mallomonas caudata	8,038
Microcystis incerta	4,160
Pandorina morum (colony)	4,160–65,000
Scenedesmus quadricauda	2,100
B. Zooplankton	
Bosmina coregoni	36×10^6
Cyclops vernalis	3×10^6–32.256×10^6
Cyclops (nauplii)	768×10^3–1.024×10^6
Daphnia pulex	128×10^6
Halteria grandinella	8,100
Keratella cochlearis	81,000

The problem of how the zooplankton can survive on a lesser volume of phytoplankton must be considered. Several theories may be presented in an attempt to clarify this problem.

Anderson, Comita and Engstrom-Heg (1955) have proposed that the phytoplankton population is controlled by the grazing of the zooplankton. High zooplankton populations are maintained by high reproductive rates of the phytoplankton. However, when the algae stop reproducing, the zooplankton population declines.

Rodhe (1955) suggests that the higher zooplankton volumes found under the arctic ice by various investigators were a result of inadequate technique. He found a very large population of microplankton, 1 to 2 μ in diameter, which escaped normal quantitative studies. Thus, the high zooplankton population might be maintained by very small phytoplankton.

Pennak (1949) found no correlation between the magnitude of algal populations and zooplankton populations. Furthermore, he concluded that food materials do not appear to be a limiting factor for zooplankton and that the relative signifi-

cance of the algae and detritus is unknown, but it is likely that the detritus is an important food source.

Edmondson (1957) also suggests that detritus has value as a nutrient for zooplankton. He believes that in distinguishing between living and dead organisms one should not lose sight of the original material. Therefore, dead plankton should not be thought of as an entity separate from the phytoplankton. However, it appears that Edmondson neglected the detritus formed from decomposition of the higher aquatic and terrestrial plants found around the body of water when he formulated this opinion.

One further food source has been denoted by Pennak (1946). He points out that in addition to eating plankton, detritus, and bacteria, certain zooplankton, especially *Cyclops*, are carnivorous and eat rotifers and other copepods.

A consideration of these publications suggests that a combination of all the above mentioned factors influences the abundance of the zooplankton. Furthermore, no one theory should be considered to be independent of the others.

SUMMARY

1. A quantitative study of the winter plankton was conducted in Urschel's Quarry, Bowling Green, Ohio.

2. Two sampling methods, the chamber method and the silk-bolting cloth method were compared. Little loss of phytoplankton occurred in the chamber method and only 0.47% of the phytoplankton, under 30 μ in diameter, were retained by the bolting cloth. In contrast, 99.89% of the zooplankton were retained by the bolting cloth. Volumes of zooplankton 2.7 times as great as those recorded by the chamber method were obtained by the silk-bolting cloth method.

3. No upward migration was noted among the nonflagellated phytoplankton. When flagellates occurred, surface samples contained 5 times as many organisms as did the samples taken at 3 m.

4. The zooplankton were found to increase in numbers and volume with depth. No diurnal migration was observed.

5. The volume of zooplankton nearly equalled or exceeded the volume of phytoplankton at most times. If other investigators would report zooplankton volumes per liter rather than numbers per liter, their results might show similar trends.

6. Insufficient evidence prevents a complete explanation of the cause of the high zooplankton volumes. However, it is most likely that the zooplankton obtain their nutrition from a combination of phytoplankton, detritus, bacteria, and carnivorous activity since no one nutrient appears sufficient to support the entire zooplankton population.

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Announcing the appearance of the second number of Volume I of the new series of Bulletins of the Ohio Biological Survey; **The Taxonomy, Distribution and Developmental Stages of Ohio Water Mites** by *Robert M. Crowell,* Assistant Professor of Biology at St. Lawrence University, Volume I, No. 2, New Series, Bulletins of the Ohio Biological Survey, pages 1–74, 143 figures.

The collections reported on were made in central and north-central Ohio during the period of 1952–1957. Nineteen species are recorded representing twelve genera and eleven families. Four species are new. An annotated list is included naming eleven species previously reported from Ohio which have not been recognized among material collected in the survey. Developmental and life history observations have been recorded. Immature stages have been recorded when they could be correlated with adult forms. Host insects are indicated for four species of water mites. Morphological details of all identified forms are illustrated. Collecting apparatus and techniques used by the writer are described and evaluated. Price of the publication is $1.25 per copy or one-half price to members of The Ohio Academy of Science. Orders with remittance should be sent to the Ohio Biological Survey, 1885 Neil Avenue, The Ohio State University, Columbus 10, Ohio.

Chemical Publications—Their Nature and Use. *M. G. Mellon.* McGraw-Hill Book Co., Inc., New York. Third Ed., 1958. x+327 pp. $7.00.

The third edition of this excellent text and reference book in the field of publications is in much the same format as the previous editions; one additional chapter, on Tertiary Sources—Guides and Directories, has been added. The well-known problems, which make this book of particular value as an instructor's guide, have been modernized. There are many excellent references to the work of *Chemical Abstracts,* yet, in some instances, the information given is inaccurate or outdated. As an example, on page 29 Dr. Mellon speaks of the 31 sections of *C.A.*; on the following pages he lists those sections; the list totals 41. On page 101 it is implied that the Fifth Decennial Index of Chemical Abstracts has already been published, when in actuality only two of the contemplated 19 volumes have appeared to date. In referring to the Russian abstract journal, *Referationyi Zhurnal, Khimiya* Dr. Mellon implies that annual formula, subject, patent, and author indexes are available. In truth, only author indexes for early years have been seen in this country. Despite these listed shortcomings, however, this volume is one with which all users of chemical literature should be familiar. For as Mellon quotes Johnson: "Knowledge is of two kinds. We know a subject ourselves, or we know where we can find information upon it."

PETER M. BERNAYS

Introductory Plant Science. 2nd Edition. *Henry T. Northen.* The Ronald Press Company. New York. pp. XII+718. Illustrated. $6.75.

The current edition of Professor Northen's textbook has many interesting and commendable features, perhaps more than the previous edition. It is a larger book by approximately a hundred pages and it contains a glossary of 21 pages. Although the chapter topics remain the same the chapters themselves have been revised and somewhat lengthened. The illustrations are especially valuable, both the carefully selected photographs and the drawings for which credit goes to I. V. Tobler the artist.

There has been an effort to eliminate the troublesome features of teleology, yet on p. 141 we read, "Some cells take on structural features which enable them to conduct water. Others become specialized for the conduction of food, and still others for food storage." A similar statement was noted in the first edition. It has not been deleted or amended. Doubtless other examples could be found. Viewing the book as a whole leaves the thought that a beginning student would have an excellent working grasp of plants in our lives and in relation to their environments from classroom discussion and mastery of the materials of this book. Particular emphasis has been placed on presenting genetics in a teachable way. This appears successfully accomplished.

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